

Geo-Environmental Monitoring and 3D Finite Elements Stability Analysis for Site Investigation of Underground Monuments. Horemheb Tomb (KV57), Luxor, Egypt.

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Research

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**GEO-ENVIRONMENTAL MONITORING AND 3D FINITE ELEMENTS STABILITY
ANALYSIS FOR SITE INVESTIGATION OF UNDERGROUND MONUMENTS.
HOREMHEB TOMB (KV57), LUXOR, EGYPT.**

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Abstract:

The Valley of the Kings (KV) is a UNESCO world heritage site with more than thirty opened tombs. Recently, most of these tombs have been damaged and inundated after 1994 flood. The Pharaonic rock-cut tombs at the valley of kings at the west bank of Luxor, were excavated mainly in the lower member I of the Thebes Limestone Formations and Esna shale Formations. These underground structures show serve degrees of damage and disintegration of supporting rock pillars, sidewalls and ceilings. In order to understand the Geo-environmental impact mainly the past flash floods in particularly the 1994 flood due to the intensive rainfall storm on the valley of kings and the long-term rock mass behavior under geostatic stresses in selected Horemheb tomb (KV57) and its impact on past failures and current stability, Remote sensing, GIS, LIDAR, 3D finite element stability analysis and rock mass quality assessments had been carried out using advanced methods and codes.

Geo-environmental monitoring and numerical analysis play an important role in the tunneling and underground works, especially for archaeological underground structures are subjected to large initial stresses and high overburden geostatic stresses. These conditions yield non-reversible deviatoric shear and creep strains that develop during time at constant stress and eventually increasing the rate of strain, namely the secondary and tertiary creep stages. Neglecting time effects may lead to incorrect evaluation of deformation, which may impact the criteria for selection of proper design. In order to describe the deformation in underground structures in the valley of kings, various approaches have been established based on analytical, empirical and numerical methods. It is clear that the tomb of Horemheb (KV57) is much more susceptible to surcharge geostatic loading from the overburden rock strata, rock bursting, and structural damage of support pillars and walls induced to the water and past/recent flash floods impacts caused by heavy rain in the Valley. Since some of this tomb also makes contact with the underlying shale layers, that have high activity and the potential for swelling and shrinkage under changing moisture conditions.

Our work provides environmental satellite space views via landviewer EOS Platform with passive and active sensors which includes the NDVI, SAVI, ARVI, GCI, NBR, NDSI, LIDAR images, Terrain DEM Digital Elevation Models, 3D geological maps. In other hand experimental and Numerical geotechnical evaluations and modeling of the rock mass of these underground structures and their surroundings have been executed. We estimated the rock mass quality of the different members within the Thebes limestone and Esna shale formations using the mechanical testing and Rock Mass Rating (RMR), rock quality system (Q-system) and Geological Strength Index (GSI) systems.

Our analyses show that the KV57 rock-cut tomb at Luxor has been cut into poor to very poor quality marl shale masses. Rock failures of ceilings and pillars were frequently facilitated by local, unfavorably oriented persistent discontinuities, such as tension cracks and faults. Other failures were related to the disintegration of the marl limestone and Esna shale Formations into individual nodules upon weathering. Our data suggest that, in ancient Egypt monumental tomb construction, low-strength rock masses rarely resulted in modifications of the planned tomb design in order to minimise the risk of rock falls and to prevent collapses. The current flood protection measures are not enough. For this two following measures are proposed 1- to rise the current wall by 50cm. 2- to fill the depression by reshaping bathymetry.

Keywords: Flash Floods, Geo-environmental investigation, Remote sensing, Geotechnical Modeling, Horemheb tomb (KV57), Valley of the Kings, Underground Monuments.

1. Introduction:

According to the Assessment of Progress in Disaster Risk Reduction, flash floods are the most widely distributed natural hazards in Egypt. They also cause huge damages in the surrounding countries. Natural disasters in Egypt include also the earthquakes, desert locust and storms.

Previous years UNESCO reports indicated, among other things, the following factors, which were considered to have a severe impact on cultural heritage properties:

- Flood hazards (valleys of kings and queens).
- High groundwater level
- Lack of a comprehensive management plan
- Major and ongoing infrastructure and development projects
- Uncontrolled urban development
- Residential and agricultural crawl or creep on the west bank of the Nile.

Great efforts have been made to preserve the archaeological site of the Valley of the Kings (KV) since UNESCO declared it a World Heritage Area in 1979. Explorations have been made to restore monuments and temples and investigate damage, degradation, and risk structures by many international groups of scientists inside and around KV (For example, Theban Mapping Project 2019, Dragowski 1988, Rutherford 1990, Verdel 1993, Lazar 1995, Wüst 1995, Fitzner et al. 2002, Hamada et al. 2004, Tawfik et al. 2010, Dupuis et al. 2011, Cuezva et al. 2016, Bardají et al. 2017, Ziegler and others. 2019). Piguet et al. 1988, Olivares et al. 2019, Hemed. 2018 summarize that Egyptian monuments mainly fail due to deterioration or cracking of building materials, weak soft soil (for example, clay), and displacement along natural fractures in hard rocks (for example, limestone, sandstone, strong clay), Or falling rock from steep slopes drifts.

The Valley of the Kings was a burial place for Egypt's pharaohs during the reign of the new king from 1550 to 1070 BC. KV is a small valley cut by heavy rain and eroded during several periods of rivers in the Eocene into a thick layer of limestone located around a sliced layer of marly shale. The valley is located at an altitude of 70 meters above the level

of the Nile River (140 meters above average sea level) and the height of the surrounding hills is 80 meters above the valley floor, as shown in Figure 1. During the late eighteenth dynasty and throughout the nineteenth century, royal tombs were usually located below the valley some distance from the rock walls. Builders often take advantage of their ankle slopes, as in the case of the Horemheb KV57 tomb. Indeed, many other royal tombs in the Valley of the Kings exhibited similar decay and disintegration features. Most of the royal tombs in the Valley of the Kings and the Western Valley were excavated in the limestone of the middle and lower part of the first Thebes' member, the lowest unit of the formation of Thebes. However, many tombs penetrate the rock and interlocking rocks found in the formation of Isna Shale. All show a advanced deterioration in the rock structure that is irreversible due to swelling and contraction. The Horemheb tomb KV57 is clearly more susceptible to the additional geostatic loading of overburden or surcharge heavy rock layers, rock bursts, and structural damage to support pillars and sidewalls and the effects of past / recent rapid floods caused by torrential rains in the valley. Since some of these tombs also come into contact with underlying shale layers, which have the potential to swell and shrink in conditions of variable humidity. Extensive damage to these underground structures was widely observed in the Valley of the Kings. This tomb KV57 tends to be the worst tomb preserved in the Valley of the Kings. The marl shale in the valley is particularly weak and unstable. Not only did the old quarry problem come up, but the modern conservators too. When the marl shale comes in contact with moisture, it expands and can literally rip the hillside. Despite being thin, being strong support elements, these shafts will continue to attract significant loads due to redistribution of stress due to drilling. Insufficient column strength can lead to extreme instability and failure

of the adjacent rock mass with potential catastrophic consequences for the associated undergrounds.

Today, satellite imagery like Guardian 2 is systematically available free of charge for large coverage, and can be used for accurate mapping as well as for documenting and analyzing historical and contemporary human activities around cultural heritage sites.

The paper represents the first comprehensive empirical and numerical studies to analyze the engineering failure and the appropriate design of the permanent mechanical support system for the Tomb of Horemheb (KV57). It is in fact one of the largest rock tombs found in Egypt.

The main characteristics of the geo-environmental and geotechnical analyzes conducted in this study are the investigation of the stable stability, safety margins, and engineering failure of the Tomb of Horemheb (KV57) under their current conditions, against the unfavorable environment (i.e. widespread weathering due to the impact of water and sudden floods in the past and present in particular the 1994 flash flood), Complete lack of protection, geostatic overload of structural rock support columns, and severe geotechnical and seismic conditions. Also to design a suitable geotechnical support system, according to the engineering rock block rating, in particular the RMR rock block rating and the Q-system index of high-quality rock tunnel.

Engineering analysis was carried out through the following four main steps: 1- Evaluation of surrounding rocks (marl limestone and marl shale) by experimental research and Roclab program to obtain the Hoek Brown and Mohr- Coulomb fit classification criterion and rock mass standards in particular the global strength and deformation coefficient. Also

to specify the main characteristics of the Esna Shale using different methods such as swelling test, swelling potential, swelling pressure, in addition, discussion of the role of the expansive Esna Shale in the deterioration of archaeological buildings and sites. 2- Quantitative and qualitative estimates of the relevant factors affecting the stability of the tomb, especially overloading, fixed, geographic, and dynamic. 3- Integrated 3D geotechnical modeling of the cemetery environment for stress and displacement analysis and identification of volumetric strains and plastic points using advanced symbols and programs such as PLAXIS 3D. 4- The repair and retrofit policies and techniques and the fixed monitoring and control systems needed to strengthen and stabilize the cemetery, where the rock mass classification refers to the rock mass where KV57 is excavated and it is poor rocks. The mechanical behavior of the rocks is simulated by assuming a foundational model to soften the elastic stress of the flexible plastic that captures fragile failure and the mechanisms of progressive substrate failure. In addition, rock pillar treatments and ground support strategies are discussed.

Based on the theory of stable engineering equilibrium and rock mass classification, support structure techniques are provided and detailed in detail with the KV57 case in this study.

2. Methods/Experimental

This section includes the aim, design and setting of the present study:

2.1 Remote sensing and GIS

Earth Observation System (EOS) platform is an advanced cloud platform has been used for the search, analysis, storing and visualization of geospatial data. This digital online Platform provided efficient tools for searching, processing, and analyzing large amounts of satellite data which have been created. As a result, valuable insights allowed us to quickly respond to changes in our area of interest (KV).

ELiT (EOS LiDAR Tool) is a sophisticated product based on the complicated algorithms for urban environment modeling and analysis. It provided the original multi-functional approach to LiDAR data processing of the Valley of Kings.

(DEM), Digital Elevation Model Generation – as a representation of the bare earth terrain with uniformly spaced z-values. The DEM tool allowed us to build a Digital Elevation Model that represents the bare earth terrain of the Valley of Kings (KV). This topographic surface is exclusively based on Airborne LiDAR Point Cloud and can be obtained in a form of either DSM (Digital Surface Model) that includes buildings, woody vegetation cover, and other objects or DTM (Digital Terrain Model) with all natural and man-made objects above the ground being removed. Topographical data used in this study is the Digital Elevation Model each cell of which consist of information of X- and Y- coordinates and evaluation Z.

2.2 Geotechnical Experimental and Numerical analyses

On the other hand, many samples of marl limestone and oil shale were examined, as the Tomb of Horemheb (KV57) was excavated through geological and geotechnical investigations, which include XRD, XRF, DTA-TGA analysis and thin-section examination under a polarized light microscope. Comprehensive petrophysical and mechanical testing

program that includes the uniaxial pressure and velocity ultrasound velocity through materials (PUNDT) test. RocLab software was used to calculate the Hoek - Brown classification and the standard also to calculate the Mohr - Coulomb fit and rock strength parameters in the deformation modulus in particular. Underground safety analysis of the KV57 is performed using finite element (FE) method. The research provides a comprehensive study to analyze the safety of rock tombs. Safety analysis not only includes failure analysis but the effect of weathering, in particular material corrosion on differential settlement, has been investigated. The commercial PLAXIS 3D FE package is used to perform stress, as well as stability analysis. PLAXIS 3D is a finite element software developed for the numerical analysis of geotechnical, underground and subterranean structures.

The deformation of this underground structure was calculated as realistically as possible, using an advanced nonlinear elastic material model that should be used in PLAXIS 3D capable of using such advanced models of materials. A 3D plastic model was used for deformation and incorporation analysis in this research. Consolidation analysis is performed using PLAXIS 3D. Rock mass classification calculations are used for general evaluation of the mass of the rock where KV57 was excavated. The Rock mass (RMR) rating results and System Q values were used to design a suitable support system.

3. Aspects of the strengthening design of the underground monuments.

Stabilization measures may include the reinforcement and rock removal; The reinforcement may consist of rock bolting, rock anchoring, dowels, shotcrete, buttresses and drainage. The rock removal consists of resloping, trimming and scaling.

The protective measures may include the wire mesh, rock fall barriers, scaling, rock sheds and tunnels.

Strengthening design of underground monuments the following aspects are to be considered:

- Type and purpose of the underground structures
- Alignment
- Site Investigation
- Topographical conditions
- Geological and hydrological conditions
- Environmental impact including, noise, vibrations and air pollution
- Legal aspect
- Safety requirements
- E& M requirements
- Geotechnical prognosis and identification of typical ground characteristics and definition of ground properties (key parameters) for analysis

- Risk assessment and analysis (Geotechnical Monitoring)

Geotechnical monitoring includes Typical 3D displacement measurement in the underground excavation and on the surface (if required), extensometers, sliding micrometers, inclinometers, transducers, electrical strain gauge, load cells for rock bolts, pressure cells, and piezometers are used to observe the system behavior. To enable a quick visualization, reliable evaluation and interpretation of monitoring results, special software like PLAXIS 3D is required.

- Selection of Support methods

- Integration of operational systems to address the underground excavation safety requirements (ventilation, firefighting).

4. Historic Context and Architectural design of Hormheb tomb (KV57)

This is the most creative realization that Horemheb left in Thebes, as the tomb itself is located within the western branch of the southwestern valley. The tomb hole is cut at the bottom of the hill and once inside, the way in is through a set of stairs cut from the rock. He combined his plan with a change in axis, as at the beginning of the dynasty, with a straight outline of the Amarna tombs. It has an area of about 110 m. The sarcophagus is about 30 meters long. Below is the entry. When approaching north from the stairs entering the burial chamber, the only deviation is in the hypostyle hall directly behind the well chamber. Here the stairs leading to the lower levels are offset to the west (opposite the western wall), but the advance is almost parallel to the upper stairs and corridors.

The burial chamber consists of two levels, the first, the upper level, which is a hexagonal hall. This leads to the lowest level, which is the actual resting place of the stone sarcophagus. Of these two sections there are nine appendices, the farthest (the farthest north) is only partially carved. The tomb was breached in ancient times. As well as digging pits through the upper passages and stairs leading to the well chamber, looters also penetrated the far wall of this chamber to reach the bottom of the tomb. The thieves are clearly not fooled by a deadly, clogged back wall.

Upon its discovery by Davis, the tomb was found to still contain many interesting items. These included red granite sarcophagus, calcite chest, and calcite. There were also many wooden statues of the gods, as well as wooden statues of the king of royal size, reminiscent of those in the tomb of Tutankhamun, but without gilding. In the chamber, known as the Chamber of Osiris, the diggers discovered the bones of two women and in the coffin, the bones of two women and another man. The remains of a man or woman were found in the coffin, whom Davis was unable to identify. Horemheb's mummy has not been found and has not yet been identified.

The decoration inside this tomb is organized as follows: (Fig. 2) Entrance corridors and stairs (A-D): not decorated. Chamber of Well (E): Scenes with the Gods. Hypostyle Hall (f): undecorated. Corridor and stairs (G-H): undecorated. Antechamber (I): Views with the Gods. Entering the burial chamber: the goddess Maat.

Burial Chamber - Column Hall (J1): The Book of Gates. Burial Chamber - Coffin Chamber (J1): The Book of Gates. Western Accessories (K-N): Part M ("The Room of Osiris") is

undecorated. Northern polyps (O-Q): not decorated. Oriental accessories (R-S): unadorned.

5. State of Preservation of Horemheb tomb (KV57)

The rock slope instabilities in the valley of kings include the plane sliding, wedge sliding, block sliding, flexural toppling and rock fall where the rock column in limit equilibrium conditions are obvious. A limestone rock column is subdivided into prismatic rock blocks of different sizes and is entirely disjointed from the rock mass behind through a system of open discontinuities. Apparently, the rock column is in limit equilibrium conditions (near to being mobilized) due to a rock bridge in the lower portion of the same rock column.

Monuments excavated in weak rock and high overburden exhibits fracturing and large deformations due to high stresses around the opening which exceed the ground strength.

The Geotechnical instability problems and degradation phenomena of rock cut tomb of Horemheb (57) in the Valley of the Kings (KV) is likely to be dominated by gravity fall and sliding on structural features, also other factors such as excessively high rock in-situ stresses, creep effect, poor petro-physical and geo-mechanical properties of marly shale structures, weathering and /or swelling rock and flash floods caused by heavy rains in the Valley, vibrations and dynamic loading as well as utter lack of preservation become important and can be evaluated by means of a classification of rock quality. The Esna shale in the valley is particularly weak and unstable. It not only posed problems to the

ancient quarryman, but to the modern conservator as well. When the shale comes into contact with moisture, it expands and can literally tear a hill side apart.

The tomb was robbed in antiquity. Since then, it has been hit by at least eleven flash floods caused by heavy rains in the Valley. These have completely filled the tomb with debris and seriously damaged its comprehensively decorated walls and pillars. In October and November of 1994, two flood events occurred in the Valley of Kings, sending a warning to all heritage managers. In both cases, a local desert rainstorm occurred in the vicinity of the Valley of Kings. Storm-water runoff and sediment entered the Horemheb tomb (KV57) and other many o tombs and caused erosion of gully floors, Table (1) summarizes the he information about 1994 flood and the inundation situation inside the effected KV tombs.

Short-term effects of rainstorms on Horemheb tomb (57) included damaged wall art due to debris flows and collapsed wall structures due to water saturation. Long term damages, however, are difficult to record, even though, their impact might be more critical. Flooded tombs like KV57 built into the Esna shale Formations, are most susceptible to rock-structure deformations or deterioration due to the physical properties of the Esna shale. Throughout the Theban Necropolis, deterioration due to swelling is a common phenomenon that can be observed in Horemheb (KV57).

The damage in KV57 due to the geostatic stresses, consists of fallen ceiling slabs, a cutout wall and door decorations, the ceiling is extremely fractured, however, crack monitors show few displacements since 1991. Crack monitors show a few millimeter (0-10mm) horizontal and to a more extent, vertical movements. Some parts of ceiling and

walls show heavy deterioration caused by rock instability due to abundant horizontal and vertical cracks.

Figure (3) represents the entrance and the main corridor of the Hormoheb tom KV57 where it is whole excavated in the marl Shale layers, Chert lenses and nodules are abundant and obvious. The In-plane deformation patterns like vertical cracks and crown zone rock falling and intensive cracking of lintel due to over loading (geostatic loading) and impact of old and modern flash floods in particular the 1994 flood, as shown in figure (4). Extensive structural damage of crown ceiling zones and engineering failure of the structural pillars, sidewalls and Ceiling of the Corridors and Chambers in the KV57. Brittle rock, high stress conditions lead to rockbursting (the sudden release of stored strain energy) bursts manifest themselves through sudden. Extensive rock falls from the ceiling is obvious and cracks are active, as shown in figure (5). Carved and decorated walls in massive Esna shale Member are in advanced state of disintegration. Showing chert lenses. The ornamented plaster on top of the chert lenses and nodules was damaged during the first flash floods that entered the tomb some 3000 years ago. During several restoration projects over the past 200 years, cracks were filled with plaster for protection and stabilization of the tomb. The impact of the 1994 flash floods on the mural paintings inside the tomb are severely obvious, as shown in figure (6).

6. GEO-Environmental Monitoring and Assessment

Environmental monitoring and assessment discusses technical developments and data arising from environmental monitoring and assessment, principles in designing monitoring

systems, and the use of monitoring data in assessing the consequences of natural resource management and pollution risks.

Recent improvements in Earth observation technologies offer advanced technical features that allow new applications especially for documentation, promotion, risk control and cultural heritage preservation. In particular, the latest spaceflight such as Sentinel-2, Landsat8 OLI + TIRS, Landsat7 ETM + Landsat 4-5 MSS and other satellites are particularly concerned with risk assessment and management, which is systematically acquired for the whole world.

This study provides the possibility of using these modern technological tools in terms of designing and planning the smart and sustainable use of cultural heritage resources. The survey showed that most of the environmental problems around the Valley of the Kings come from previous torrential floods due to rainstorms, high level of groundwater depth and the main reason is unplanned urban sprawl. The results of our analysis showed that the Valley of the Kings is located in the Western Desert with less rainfall and frequency in the Nile River Basin in Egypt. Previous research suggests that storm duration exceeds one to two hours. Most of the storms are of low intensity rain since 1994. However, severe rainstorms have been observed in recent years due to the impact of climate change. At the moment, there is a possibility that a severe storm like one or more of the year 1994 could have dire consequences especially in these tourist areas. Previous research suggests that the rainfall intensity of the 1994 storm was about 16 mm / hour within two hours.

The results of our analysis using the data obtained showed the spatial dimension of the changes in urban and agricultural areas, which were clearly visible in the classification

images and the extracted indicators. Sustainable management and exploitation as well as conservation and mitigation strategies are mandatory to reduce decomposition phenomena, threats and human actions that may accelerate decay dynamics or lead to degradation and / or significant alteration of the rock tombs of the KV and its "environment". In this context, remote sensing techniques can provide useful data for timely updating of information and documentation as well as reliable tools for systematically monitoring cultural property. The massive availability of advanced remote sensing data today has opened new and unexpected challenges for several years. Especially, for archaeological sites and landscape remote sensing, it can provide useful data not only for exploring the Earth's surface to discover sites and artifacts, but also for management, evaluation and conservation, for detecting changes as well as for assessing degradation and emerging threats.

Figure (7) represents an Urban Image. This band combination also provides a "natural-like" rendition while also penetrating atmospheric particles, smoke and haze. Vegetation appears in shades of dark and light green during the growing season, urban features are white, gray, cyan or purple, sands, soils and minerals appear in a variety of colors. The almost complete absorption of Mid-IR bands in water provides well defined and highlighted sources of water within the image; water is black or dark blue. Hot surfaces such as forest fires saturate the Mid-IR bands and appear in shades of red or yellow. One particular application for this combination is monitoring fires. Flooded areas should look very dark blue or black. Figure (8) represents a band combination which is good for picking out land from water. In this false color image, land appears in shades of orange and green, and water appears in shades of blue. Figure (9) represents an Index stack; It becomes readily

apparent in this image stack that particular colors can be equated to different landscape features. For example, vegetation displays here as green, water as purple, and soil, rocks, and barren land as blue. Clouds also appear as a mixture of purple and magenta, so in this case these indices alone are not sufficient for differentiating clouds from water. Figure (10) represents The classification map which includes four different classes for clouds (including cirrus) and six different classifications for shadows, cloud shadows, vegetation, soils/deserts, water and snow provision of associated quality indicators corresponding to a map of cloud probability and a map of snow probability.

7. The Geology of Gebel El-Gurnah, Luxor

The Thebes were deposited in a shallow deep marine environment. The lowest Paleolithic to the early Eocene periods of Western Thebes consisted of three formations: the members of Trawan, Esna, and Thebes. Distinctive weathering was used to form the goodness to divide the composition of the good into four units, the first member of the fourth member. The displacement of 30 m of the first member associated with the rift of the Valley of the Kings is located on the right side, about 40 meters from the tomb of Amenemis (m10), and these formations were deposited in the southern part of Tethys, and the sea connecting the Atlantic and Indian Oceans, which was closed during the collision Continental between the Alps and Africa. Figure 12 represents the digital elevation model of the Valley of the Kings and Jebel Qurna. Figure (13) Stratification in the West Bank. The location of the selected tombs in this caliphate is shown here. The tombs of KV17, 20, TT353 and 192 are located in semi-horizontal rocks. P, Pallucene. E, Eocene.

Jabal Al Qurna is located 4 km west of the Nile, opposite the city of Luxor. The main exposed rock units at Jebel Qurna are the limestone formations of Isna Shail and Thebes. The tombs of the kings were excavated in the Theban Formations on the northern side of Jebel Qurna and the tombs of the queens were excavated on the southern side (Dunn, 2014., Wust and Macline 2000).

The main exposed rocks of Jebel Qurna are the Esna Shale (late Paleocene - early Eocene) and the mutually compatible composition from Thebes (early Eocene).

Esna rock: The bottom 25 m of this formation is less calcareous, usually dark green gray, sometimes rough. The upper rocks are greyish-green, more compact and hold more gypsum. Iron oxides vary in color. There are red, yellow, brown and lemonade stones. Plaster strips run parallel to the bed planes. (Wust and Maclane, 2000), as shown in Fig. 14. This represents the sudden association of the Abu Hadd member in the Isna rock formation with the stone unit 1 of the Thebes limestone formation. The photo was taken just above the KV57 site.

The Esna rock formation is divided into four distinct stone units from top to base (Dupuis et al., 2011): 1) Abu Hadd (alternation of marl and limestone basins with few periods of clay. It is lighter in color and richer in carbonates than 2) Reserve member (dark mudstone). 3) fog quarry member (dark gray rock from 0.6 to 3.7 m). 4) Hanadi member (massive light gray rock).

The Taiba Formation: The Taiba formation in the Valley of the Kings can be divided into three members (from the base to the top), the members of Hamada, al-Bayda, and al-Jeer. However, the formation of Thebes above the rock. The lower part of Hammadet is made of

white and chalky limestone combined with concrete stone, the middle member of Bida is made of thick agglomerate limestone, with extended flint bands parallel to the bed layers, and the upper member Al-Geer is mainly made of white limestone, (Aubrey et al., 2008) & Celotti, 1997).

There are many faults in the southwest corner of the Valley of the Kings. It is very complex in nature. The number of faults cuts into the limestone formations of the Eocene. Typically, these breaks cause various cross-slip problems, and the veins around the crystal calcite have developed into the overlapping spaces. Calcite may be rigid as well as bypass structures, which provide the course more rationally than request a voucher.

Regular defects, showing evolution of the northeast-west trend plane, are abundant. However, a fatal flaw, on the northwest side of the canyon, may be the predominant (and left-handed) glide, while others require diagonal assistance (left-to-right rotation, regular right-turn rotation). Although these five measured errors are not sufficient, they will have a chance to be statistically significant. When brittle rocks lead to high pressure conditions, the rock bursts (the sudden release of stored stress energy) that manifests itself suddenly.

Figure (15) is an indication of the erosion caused by the rapid flooding of the shale stratum and vertical fissures in Unit 1 of the limestone at Thebes, and the identification of abandoned excavations and its bridge. The semi-vertical wall pieces were excavated at the top of the shale formation and at the base of the limestone formation at Thebes. White arrows indicate erosion grooves at the bottom of the first unit of the Thebes Formation, in the Hanadi member (the Esna rock formation) and in the debris covering the Esna Formation. Note that the grooves in the base of the limestone at Thebes and slightly below

are generally hollow, particularly at the top and bottom of the protruding base of Unit 1.

These are possible signs of a flash flood. Deciduous blocks are unstable columnar mass and open columnar fractures; Degrees. Dunes resulting from archaeological excavations.

8. Results and discussion of the experimental investigations:

8.1 Mineralogical and Geotechnical properties of intact marl limestone and marly Shale specimens and discontinuities

The tomb was cut into a south-facing flank of the lowermost unit of the Thebes Formation.

The tomb is built into Esna shale Formation, 152.59m asl.

Eight thin sections were examined using a polarized optical microscope to determine the petrographic and geochemical properties of these building materials (Marl limestone and marly Shale). X-ray diffraction sensors (XRD) and X-ray probe (XRF) were performed to determine slats and proportions of the fixing limestone and Shale. In addition to the electron microscopy (SEM) attached to the energy dispersed x-ray (EDX) for microscopy and microscopy. Examples of XRD diffraction are increased for both studied stones and slurry tests by Cu K. radiation. The filtering speed is $2\theta = 1^\circ / \text{min}$. With a constant voltage of 40 kV, 30 m and using X-ray diffraction PW 1480. Important components (by weight%) of the studied stone and rock tests were performed using X-ray fluorescence spectroscopy (XRF) along an advanced wavelength - dispersive spectroscopy (Axios, WD-spectroscopy) XRF, PANalytical, 2005, Netherlands). Chemical analyzes were performed using the ASTM specification (ASTM C114-00, (ASTM C114-15))), and electron

microscopy images (SEM) were performed on a smaller analyzer JXA 840A for electron testing, Japan,

The engineering properties of the studied building materials were achieved. 13 cylindrical samples of limestone and marly Shale were prepared to determine the petrophysical and geochemical properties. Specific gravity (G_s), Bulk unit weight (γ_b), water absorption (W_c), porosity (n) and saturation (S_r) are the specified physical aspects. While mechanical characterization involved determining the uniaxial compression force (σ_c), Young (E) coefficient and discrete Brazilian tensile strength (σ_t), shear cut (T), and Schmidt hammer index (SHV) number, strength or impact indicators are estimated By AIV, in addition to testing non-destructive ultrasound velocity (V_p) by stone examples, Young's dynamic coefficient (E_d) and shear modulus (G).

Mineralogical study

The upper Esna Shale II unit is composed of marl and shale interbeds. The marl interbeds of Esna Shale II and the marls of Member I have similar compositions. The marls of Esna Shale II have 65–70%calcite and 30–35%clay minerals.

The clay minerals are mainly palygorskite (50– 80%), kaolinite (10%) and illite/smectite mixed layers (10–40%). The mineralogical composition of the shales is 5–25%calcite, 5–10%anhydrite and 70–80%clay minerals. The clay minerals are predominately illite/smectite mixed layers (40– 75%), palygorskite (20–50%), kaolinite (<10%) and illite (<10%). The lower unit of the Esna Formation, Esna Shale I, has up to 20%calcite and up to 95%phyllosilicates, with 3–10%anhydrite. The clay minerals are composed of about

70%kaolinite, 25–35%illite/smectite mixed layers and minor amounts of palygorskite and illite, as shown in figure (16).

In the four samples analyzed, calcite (marl) and clay minerals (shale) are most abundant with minor amounts of quartz. The detected clay minerals are mixed-layer smectite, palygorskite and sepiolite. The clay minerals account for up to 80% of the mineral composition in the shales.

Small amounts of quartz, abundant palygorskite and little sepiolite were detected in the marl of the lowermost part of Member I. The clay mineral composition is 10%sepiolite and 90% palygorskite.

The XRD analysis indicated that the major contents of Esna shale are quartz (SiO_2) and Montmorillonite ($\text{Na}_{0.2} \text{Ca}_{0.1} \text{Al}_2 \text{Si}_4\text{O}_{10} (\text{OH})_2 \cdot (\text{H}_2\text{O})_{10}$), the minor contents include the Kaolinite and Illite with Calcite traces, as shown in tables (2 and 3). The X- ray Diffraction results showing the clay minerals of natural or air treated untreated clay fractions sample from Esna shale Member, where the Horemheb tomb (KV57) is excavated are Montmorillonite 77%, Illite 20% and Kaolinite 3%, as shown in Figure (17) and tables (4). Table (5) summarizes the X- ray Diffraction results of three shale samples in the three levels from Esna shale Member at the site of KV57. Figure (18) represents the XRD for the air dried, ethylene glycol treated, and heated to 550C clay fractions from samples of Esna shale, showing decrease and disappearance of peak of Illite/Smectite (I/S) and the present of the Montmorillonite.

Thin-sections prepared on the marl limestone and Esna shale samples where the KV57 is excavated. C.N. Microscopic photograph shows the marl sample from Member I is very fine-grained to fine-grained. Considerable amounts of cavities and microvioletlets filling by recrystallized dolomite are observed in the micritic calcite matrix. The rock is very to fine-grained and composed mainly of calcite and dolomite as the essential components associated with minor amount of clay minerals and rare amounts of microcrystalline quartz, iron oxides and opaques. Calcite represents the matrix of the rock and occurs as very fine-grained (micrite), anhedral to subhedral interlocked crystals. Dolomite occurs as very fine to fine-grained, euhedral to subhedral crystals and filling microvioletlets and cavities. Quartz is detected as very fine-grained crystals scattered in the matrix. Some pores of irregular shapes and various sizes are observed scattered in the rock. Some parts of the sample are stained by iron oxides, as shown in Figure (19). C.N. Microscopic photograph shows the Esna shale sample is very fine to fine-grained (mainly sand size), well sorted that is cemented by minor amounts of iron oxides, clay minerals and carbonates. The sample is porous where pore spaces of different sizes are observed. The rock is composed mainly of quartz and feldspar grains cemented by minor amounts of iron oxides, clay minerals and calcite. Rare amounts of muscovite, biotite, hornblende and opaque minerals are observed in the sample. Quartz occurs as very fine to fine grains of subrounded to angular shape. Feldspars occur as fine grains that are observed in different parts of the sample. Opaque minerals occur as very fine to fine-grained crystals, scattered in the sample. Some parts of the sample are stained by traces of iron oxides, as shown in figure (20).

Geotechnical study

Marl limestone: Petro-physical properties: Physical measurements referred that the unit weight (γ) of marl limestone of KV57 is between 20 and 21 kN/m³, water absorptions (W_a) were between 10 and 12% and the apparent porosity (n) ranged from 14 to 19%.

Shear Wave Velocities (V_s): Shear wave velocities of limestone samples were measured by PUNDT (ASTM 597, ASTM D 2845-83). They varied from 0.7 to 0.9 km/s (with an average of 1 km/s for an orientation perpendicular on the bedding plane).

Uniaxial Compression Test: The compressive strength (σ_c) for the sidewalls is between 8 and 9 MPa.

The static Young's modulus (E) = 12GPa, Poisson Ratio (ν) = 0.25-0.30, figure shows the test set and the results are summarized in table (6).

Esna shale: The physical properties includes, The bulk unit weight of the Esna shale is 1.79 to 1.86 g/cm³, and the uniaxial compressive strength is 4.22 to 4.43 kg/ cm², the specific gravity $G_s = 2.7$, the void ratio $e_i = 1.86$, $\gamma_d = 17-18$ N/m³, $\gamma_b = 18-20$ N/m³, water content 8-10%, OMC 14-16%, LL 75-80%, PI 422-432 %, clay % 70-80. The Esna shale has poor elastic parameters, where the static modulus of Elasticity $E = 1500- 2000$ kN/m² and the Poisson's ratio $\nu = 0.3- 0.4$. For the shear strength parameters for this also very poor, where the cohesion of grain particles $c = 30$ kN/m², and the internal friction angle $\phi = 25$. Free swelling % 100 -180, and swelling pressure 710-742 kPa. The Activity % is 1.5 - 2 . Results are summarized in tables (7).

Long term swelling test on Esna shale samples revealed an enormous water absorption and swelling capacity. Swell heaving is between 50% and 80%. Most of which take place within the first hour. The swelling pressure exceeds 5 MPa and 13 MPa with deformations of 1.5 and 3.3%, respectively. Table (8) summarizes the geotechnical properties of the intact marl limestone samples with depth and the shear parameters of the discontinuities of the rockmass where the Horemheb tomb (KV57) is excavated.

According to the ASTM C568 / C568M-15 the physical characteristics of the marly limestone and marly Shale are low, since the water absorption by weigh/max must be in range of 3% for the low density limestone to 12 % for the high density limestone.

According to the ASTM C 170, C 880, C 99 test methods and ASTM C568 / C568M-15 specifications, the physical and mechanical characteristics of the marly limestone and marly Shale is low, since the standard requirement for the uniaxial compressive strength (σ_c) of the limestone must be in range of 12 MPa for the low density limestone to 55 MPa for the high density limestone, (Hemeda, 2020).

8.2 Analysis of rock mass strength using RocLab Program

RocLab is a software program for determining rock mass strength parameters, based on the latest version of the generalized Hoek-Brown failure criterion.

Hoek-Brown Classification: Intact uniaxial compressive strength of intact marly limestone (σ_{ci}) = 8 MPa, GSI geological structure index = 50, intact modulus (m_i) =9, disturbance factor (D) = 0, intact rock deformation modulus E_i = 12000 MPa, modulus ratio (MR) =500.

The generalized Hoek-Brown Criterion failure criterion: $mb= 1.509$, $s= 0.003866$. $a= 0.50573$, where (s) and (a) are constants of the rock mass, calculated from the geological strength index (GSI) and disturbance factor (D).

Mohr-Coulomb Fit: Cohesion $c= 0.3859$ MPa, Friction angle $\phi= 29.62^\circ$

Rock mass parameters: Tensile strength of intact rock $\sigma_t = -0.016$ MPa, Uniaxial compressive strength 800 kPa, as shown in Figures (21) and (22). Table (9) summarizes the Hoek Brown classification, Hoek Brown Criterion, Failure Envelope Range, Mohr-Coulomb Fit and Rock mass parameters for the marl limestone member 1 where the entrance Horemheb tomb (KV57) is excavated, using the RocLab program.

9. Results of the 3D Numerical Analysis and Geotechnical Modeling:

In this study, PLAXIS 3D was performed to determine the behavior of rock formations under severe geostatic stresses. Plaxis is a commercially available software that uses the FEM Finite Element method. Plaxis uses different soil / rock models to define soil / rock behavior such as the Mohr-Coulomb model, the solidified soil model, the loose soil model, the soft soil crawl model, the common rock model, and the modified Cam-Clay model. Soil hardening model was chosen for this study.

Soil hardening model is an advanced model for simulating soil behavior. For the Mohr - Coulomb model, the stress states defined by the angle of friction ϕ , coherence c , and the expansion angle ψ are described. However, soil hardness is more precisely described

using three different types of input hardness: E50 triaxial hardness, European triaxial dumping hardness, and Ooed counter loading hardness. In contrast to the Mohr - Coulomb model, the solidified soil model also explains the dependence of stiffness parameters on stress. This means that all stiffness increases with pressure. Hence, the stiffness of the three inputs relates to the reference pressure, and is usually taken as 100 kPa (1 bar).

Besides the above model parameters, initial soil conditions, such as pre-consolidation, play an essential role in most soil deformation problems. This can be taken into account when generating the initial pressure.

Low strength rock formations where KV57 has been critically drilled in dangerous safety conditions under steady loading and earthquake conditions. PLAXIS 3D was used for 3D numerical analysis of central main chambers with structural supportive rock columns being damaged structurally. Vertical cracks due to overload and force slope are evident.

The aim of the 3D test is to assess the pressure condition in the columns while observing the 3D geometry. The issue of 3D influences on basic design methodology is considered in the following areas. The various repetitions shown were repurposed with the PLAXIS 3D (PLAXIS 3D) code.

The results of the three-dimensional static analysis represented in Figure. (23) to Figure. (31) Indicate that the rock columns in the main chambers are subject to relatively high pressure pressures. The main effective calculated compression peak pressure for rock columns and supporting side walls is 5.52×10^3 kN/m² as shown in Figure (23). The maximum effective vertical compressive pressure calculated on rock columns and

supporting side walls is $8.7 \times 10^3 \text{ kN/m}^2$ as shown in Figure (24). The effective horizontal mean presses $4.94 \times 10^3 \text{ kN / m}^2$ as shown in Figure (25). Figure (26) represents the plastic dots (Mohr-Coulomb and Tension cut points) for the roof, the supported rock columns and the sidewalls of KV57. The total displacement of the roof and pillar areas is 30.92 mm as shown in Figure (27). The vertical displacement is 30.76 mm as shown in Figure 28. The horizontal displacement is 15.52 mm as shown in Figure (29). The total incremental displacement is 1.07 mm as shown in Figure (30) and the volumetric strain is 1.45% as shown in Figure (31).

The results showed that the values of stress and displacement distribution on the roofs and structural rock pillars did not increase due to the excavation process extending behind the main hall and this may be due to the lower level of the ceiling for these small burial chambers. Numerical results suggested that failure could be more influenced by the orientation of vertical joint sets rather than bedding planes.

The numerical analysis reveals that the roof of the tomb which has suffered from exfoliation is those in compression. Given that the exfoliation is the result from a combination of the fluctuation of humidity and compressive stresses, the study concludes that the fluctuation of humidity needs to be minimized by preventing the active circulation of air through the tomb.

Pillars axial stress versus displacement curves provide insightful information on pillar failure mechanism associated with increasing axial loads. It can be seen that for pillars with $W/H = 1/3 \leq 0.5$ the pillars generally exhibit a linear elastic behaviour up to

peak strength then a brittle failure followed by an approximate perfectly plastic post-peak behaviour.

The results indicate general agreement with the empirical relationship for pillar width to height ratios. On the other hand, there is a significant reduction in pillar strength for ratios $W/H < 0.5$. In these cases and where the pillar stability is controlled by unfavourable defects.

10. Evaluate the safety factor and stress state in the structural support pillars

$$\text{Factor of Safety} = \text{FoS} = \frac{\text{Strength of Material}}{\text{Max Computed Stress}} = \frac{\text{Failure Stress}}{\text{Actual Stress}}$$

FoS > 1 is The design criteria the engineering component/structure must achieve.

The designer defines failure; component/structure doesn't meet performance criteria;

e.g. excessive deformation, fracture, etc.

In general, Use higher FoS for brittle materials (to avoid catastrophic failure). Use lower FoS when using materials for which the material properties are very well known. Use higher FoS for uncertain environments/stresses.

Typical Values for the Factor of Safety (FoS) of the buildings is ≥ 2 . Bolts ≥ 8.5 .

It is demonstrated that induced stresses of significant magnitude and ambiguous distribution are to be expected in the supporting pillars. Multiple openings and excavations designed on the basis of the average stress in the pillar σ_v given by the tributary area theory, as explained in equation (1).

$$\sigma_p = \frac{A_t}{A_p} \sigma_v \quad (1)$$

Where,

- A_t is the area supported by the pillar
- A_p is the area of the pillar
- σ_v is the vertical stress at the level of the roof of the excavation (catacombs)

To evaluate the degree of safety of a pillar, we must compare the above average pillar stress σ_p with the pillar strength σ_p . The latter is not simply the unconfined compressive strength of the material comprising the pillar q_u , because shape and size effects introduce significant modifications from the breaking strength of unconfined compressive cylinders.

The strength in compression for rectangular pillars of square cross section can be estimated from the equation number (2).

$$\sigma_p = \left\{ 0.875 + 0.250 \frac{W}{H} \right\} \left\{ \frac{h}{h_{crit}} \right\}^{0.5} (q_u) \quad (2)$$

Where,

- σ_p is the strength of the pillar,
- W and H are the width and height of the pillar respectively,
- q_u is the UCS strength of the pillar material on cylinders with height (h) equal to twice the diameter and

- h_{crit} is the minimum height of the cubical specimen of pillar material such that an increase in the specimen dimension will produce no further reduction in strength.

For the pillars, see figure (24), $\sigma_v=8.7$ MPa, $A_t = 2$ m² and $A_p = 1$ m² we can derive:

$$\sigma_v = \frac{2}{1} \times 8.7 = 17.4 \text{ MPa}$$

The strength of the pillar σ_p can be estimated from the equation: For the pillar we have $W=1$ m, $H=3$ m. If we assume $h_{crit}=0.2$ m and $h=1$ m for $q_u = 8$ MPa, we have $\sigma_p = 17$ MPa

And the Factor of Safety $F. S = \frac{\sigma_p}{\sigma_v} = \frac{17}{17.4} = 0.97$ which very low and indicate to the dangerous and unsafe situation and losing of the structural function of these load bearing pillars. Hoek and Bray quote Salamon and Munro's suggestion of acceptable safety factors > 1.6 . Such values may be adequate for the excavation stability, (Hemeda et al, 2010, Hemeda, 2018).

$$\text{Also overstress state} = \frac{\sigma_c}{\sigma_v} = \frac{8 \text{ MPa}}{8.7 \text{ MPa}} = 0.9 \quad (3)$$

The tributary theory is based on average pillar stresses and derived stress value is generally close to the averages predicted by PLAXIS 3D. On other hand, the overloading of geostatic loading due to the overburden strata on the supporting rock pillars is obvious and it induced critical vertical cracks in these pillars also some sections have an overriding influence on the pillar stability, equation 3, particularly in terms of long-term creep effects and associated strength loss or thinning-out of the effective load bearing pillars and section, (Hemeda, 2008, Hemeda, 2019). In the original study of Salamon and Munro this occurred between safety factors of 1.3 to 1.9 with the mean being 1.6. This value was

recommended for the design of production pillars in South African bord and pillar workings (Salamon and Munro, 1967).

11. Design of structural supporting systems:

In order to effectively manage these large deformations, a number of important strengthening design parameters must be established. These include definition of the over-excavation required to provide deformation allowance, as well as determination of support measures. A support system which allows controlled deformations is chosen to limit the required support resistance and to achieve stability.

The Rock Mass Rating classification system relies on a group of six parameters = Intact rock strength, RQD, joint spacing, joint conditions, groundwater and modulus.

The first option is based on the calculation of Bieniawski, s RMR (Bieniawski, 1989) (rock mass classification system), where the strength of sound rock is 8 MPa (at a rate of 1), the RQD is 50 (at a rate of 12), and the joint spacing is less than 60 mm (5), the interruption conditions are 1-5 mm separation with continuous joints (at a rate of 10) and the groundwater conditions are completely dry (at a rate of 14), to adjust the direction of the joint is -5 and then RMR from the tomb of the sons of Ramses II (37) which are classified as rocks Poor with high pressure, as shown in Table (10).

Pillar Stitching

Pillar stitching with high strength rock bolts provide a significant increase in pillar strength. If a weaker rock layer exists in the pillar, the benefits of pillar stitching were mainly observed as a post-peak behaviour resulting in a more controlled failure, particularly for $W/H > 0.5$.

According to the calculated RMR value and the guidelines for drilling and supporting 10-meter long rock tunnels according to the RMR system (after Bieniawski 1989), as summarized in Table (11), the complete column support system design KV57 can include systematic rockbolt 4-5 meters long, Spaced between 1 and 1.5 m in the crown and walls with a wiremesh 100-150 mm in the crown and inside 100 mm with light to medium ribs of 1.5 m as needed.

Conclusions:

In conclusion, the characteristics of the rock mass and the environmental conditions of the area were collected to make a preliminary stability assessment of the Eighteenth Dynasty Tomb KV57. A digital 3D model was developed in PLAXIS 3D using the solidified soil modeling method, which indicates the importance of bulge pressure and vertical joints on the underground structure stability of KV57.

Detailed geo-environmental monitoring of remote sensing accompanied by detailed geotechnical analysis of the Tomb of Horemheb KV57 in Luxor, Egypt, showed that these unique underground structures provide low static safety factors for the structurally damaged roof and rock columns under the current conditions of geostatic stress. Where the FS is about 0.97, (note that the acceptable safety factor for underground structures is >

1.6 in the steady state). The overpressure condition of the surrounding rocks exceeds the elastic system (field boundaries), and all structural supports of the roof, side walls and rock pillars are subjected to high vertical pressure stresses due to the high stresses in the site and weak geotechnical properties of marl limestone and oil shale. Several instability issues for static and dynamic loading were recorded and analyzed. As a result, a well-focused reinforcement and modification program is essential and urgently required since KV57 is closed due to instability and unsafe conditions.

Figures Legend

Figure.1. LIDAR image, The Ratio "VV, VH, VV / VH" combination works well for distinguishing water objects, open soils, moistened agricultural fields, vegetation, and urban areas. Water in lakes is shown in dark blue, bright blue or black hues with radar signal noise. Blue hues show agricultural fields with bare soil, often sufficiently waterlogged. Fields with vegetation show a green color. Buildings of a metropolis are represented by bright green-yellow shades.

Figure.2. 3D Sketchup model for the Horemheb tomb, Luxor, Egypt (KV57).

Fig.3. the entrance and corridor of the KV57 where it is whole excavated in the marl Shale layers, Chert lenses and nodules are abundant and obvious.

Fig.4. In-plane deformation patterns like vertical cracks and crown zone rock falling and intensive cracking of lintel due to over loading (geostatic loading) and impact of old and modern flash floods in particular the 1994 flood.

Figure.5. Extensive structural damage of crown ceiling zones and engineering failure of the structural pillars, sidewalls and Ceiling of the Corridors and Chambers in the KV57. Brittle rock, high stress conditions lead to rockbursting (the sudden release of stored strain energy) bursts manifest themselves through sudden. Extensive rock falls from the ceiling is obvious and cracks are active wher the gypsum Pegs are cracked and broken.

Fig. 6. Carved and decorated walls in massive Esna shale Member are in advanced state of disintegration. Showing chert lenses. The ornamented plaster on top of the chert lenses and nodules was damaged during the first flash floods that entered the tomb some 3000 years ago. During several restoration projects over the past 200 years, cracks were filled with plaster for protection and stabilization of the tomb. The impact of the 1994 flash floods on the mural paintings inside the tomb are severely obvious.

Figure.7. Urban Image. This band combination also provides a "natural-like" rendition while also penetrating atmospheric particles, smoke and haze. Vegetation appears in shades of dark and light green during the growing season, urban features are white, gray, cyan or purple, sands, soils and minerals appear in a variety of colors. The almost complete absorption of Mid-IR bands in water provides well defined and highlighted sources of water within the image. water is black or dark blue. Hot surfaces such as forest fires saturate the Mid-IR bands and appear in shades of red or yellow. One particular application for this combination is monitoring fires. Flooded areas should look very dark blue or black.

Figure.8.This band combination good for picking out land from water. In this false color image, land appears in shades of orange and green, and water appears in shades of blue.

Figure.9. Index stack. It becomes readily apparent in this image stack that particular colors can be equated to different landscape features. For example, vegetation displays here as green, water as purple, and soil, rocks, and barren land as blue. Clouds also appear as a mixture of purple and magenta, so in this case these indices alone are not sufficient for differentiating clouds from water.

Figure.10. The classification map which includes four different classes for clouds (including cirrus) and six different classifications for shadows, cloud shadows, vegetation, soils/deserts, water and snow provision of associated quality indicators corresponding to a map of cloud probability and a map of snow probability.

Figure.11. Location of the Horemheb tomb (KV57) at the east (main) Valley of the Kings (KV), Luxor Egypt. Stratigraphical succession as seen. Characteristic weathering of the Thebes Formation was used to subdivide the Thebes Formation into four units, Member I to Member IV. A 30 m displacement of Member I associated to the Kings Valley Fault is located on the right-hand side approximately 40 m from the tomb of Amenmesse (KV10).

Figure.12. (DEM), Digital Elevation Model of the valley of kings and the Gebel Gurnah.

Fig. 13. Stratigraphical succession on the West Bank. We show here the location of selected tombs in this succession. Tombs KV17, 20, TT353 and 192 are located in the sub horizontal bedrock. P, Paleocene; E, Eocene.

Fig. 14. Abrupt contact of the Abu Had Member of the Esna Shale Formation with lithological unit 1 of the Thebes Limestone Formation. Photo taken just above the location of the KV57

Fig. 15. Evidence of flash flood related erosion in the Esna Shale and vertical fissures in Unit 1 of the Thebes Limestone, delineation of the abandoned Excavations and its causeway. The subvertical wall-cuts were dug in the upper part of the Esna Shale Formation and at the base of the Thebes Limestone Formation. White arrows point to erosional gullies in the lower part of unit 1 of the Thebes Formation, in the Hanadi Member (Esna Shale Formation) and in the debris that cover the Esna Formation. Note that the gullies at the base of the Thebes Limestone and just below are commonly hollowed out, in particular on top and below the prominent base of Unit 1. These are probable evidence of flash floods. fallen blocks; unstable columnar block and open vertical fissures; screes. screes resulting from archeological excavations.

Figure.16. X- ray Diffraction results showing the bulk Mineralogy of Marl Shale (Calcite/ Smectite) where the Horemheb tomb (KV57) is excavated.

Figure.17. X- ray Diffraction pattern showing the clay minerals of natural or air treated untreated clay fractions sample from Esna shale Member, where the Horemheb tomb (KV57) is excavated.

Figure.18. XRD for the air dried, ethylene glycol treated, and heated to 550C clay fractions from samples of Esna shale, showing decrease and disappearance of peak of Illite/Smectite (I/S) and the present of the Montmorillonite.

Figure. 19. C.N. Microscopic photograph shows The marl sample from Member I is very fine-grained to fine-grained. Considerable amounts of cavities and microvioletts filling by recrystallized dolomite are observed in the micritic calcite matrix. The rock is very to fine-grained and composed mainly of calcite and dolomite as the essential components

associated with minor amount of clay minerals and rare amounts of microcrystalline quartz, iron oxides and opaques. Calcite represents the matrix of the rock and occurs as very fine-grained (micrite), anhedral to subhedral interlocked crystals. Dolomite occurs as very fine to fine-grained, euhedral to subhedral crystals and filling microvioletlets and cavities. Quartz is detected as very fine-grained crystals scattered in the matrix. Some pores of irregular shapes and various sizes are observed scattered in the rock. Some parts of the sample are stained by iron oxides

Figure. 20.C.N. Microscopic photograph shows the Esna shale sample is very fine to fine-grained (mainly sand size), well sorted that is cemented by minor amounts of iron oxides, clay minerals and carbonates. The sample is porous where pore spaces of different sizes are observed. The rock is composed mainly of quartz and feldspar grains cemented by minor amounts of iron oxides, clay minerals and calcite. Rare amounts of muscovite, biotite, hornblende and opaque minerals are observed in the sample. Quartz occurs as very fine to fine grains of subrounded to angular shape. Feldspars occur as fine grains that are observed in different parts of the sample. Opaque minerals occur as very fine to fine-grained crystals, scattered in the sample. Some parts of the sample are stained by traces of iron oxides

Figure.21. Major and minor principal stress curve of marl limestone (KV57) using the RocLab program.

Figure. 22. Shear stress-Normal stress curve of Marl limestone (KV57), using the RocLab program.

Figure.23. Effective mean stresses for the supported rock pillars and sidewalls in KV57, the extreme value is $5.52 \cdot 10^3 \text{ kN/m}^2$.

Figure.24. Vertical stresses (σ_{yy}) for the supported rock pillars and sidewalls in KV57, the extreme value is $8.70 \cdot 10^3 \text{ kN/m}^2$.

Figure.25. Horizontal stresses (σ_{xx}) for the supported rock pillars and sidewalls in KV57, the extreme value is $4.94 \cdot 10^3 \text{ kN/m}^2$.

Figure.26. Plastic points (Mohr-Coulomb and Tension cut-off points) for the supported rock pillars and sidewalls in KV57.

Figure. 27. Total displacement (U_{tot}) for the supported rock pillars and sidewalls in KV57, the extreme value is 30.92mm.

Figure.28. Vertical displacement (U_y) for the supported rock pillars and sidewalls in KV57, the extreme value is 30.76mm.

Figure.29. Horizontal displacement (U_x) for the supported rock pillars and sidewalls in KV57, the extreme value is 15.52mm.

Figure.30. Total incremental displacement (dU_{tot}) for the supported rock pillars and sidewalls in KV57. The extreme value 1.07mm.

Figure.31. Volumetric strains for the supported rock pillars and sidewalls in KV57. The extreme value 1.45 %.

Declarations

a. Acknowledgements;

Not applicable

b. Availability of data and materials;

Not applicable

c. Competing interests;

The author declare that he has no competing interests

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e. Authors contributions;

The whole database construction and analysis are presented in the manuscript had been achieved by the author. The author read and approved the submitted manuscript.

f. Authors Affiliations;

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g. Availability of Supporting Data;

"Data sharing not applicable to this article as no datasets were generated or analyzed during the current study".

h. Competing Interest;

"Authors have no competing interests to declare"

i. List of Symbols and Abbreviations;

Symbols

- At** is the area supported by the pillar
- Ap** is the area of the pillar
- σ_v** is the vertical stress at the level of the roof of the excavation (KV5)
- σ_p** is the strength of the pillar,
- W** and **H** are the width and height of the pillar respectively,
- qu** is the UCS strength of the pillar material on cylinders with height (h) equal to twice the diameter
- h_{crit}** is the minimum height of the cubical specimen of pillar material such that an increase in the specimen dimension will produce no further reduction in strength.
- β** Angle between the normal to the fracture plane and the horizontal plane
- ϕ** Friction angle of the fracture
- τ** Shear stress in resin annulus
- σ_b** Applied stress
- α** Decay coefficient 1/in which depends on the stiffness of the system
- β** Reduction coefficient of dilation angle
- σ_c** Uniaxial compressive strength of rock
- A_j** Joint area
- ϕ_b** basic joint friction angle
- D_s** Rib spacing
- U** The shear displacement at each step of loading
- c** Cohesion between block joints

σ_n	Normal force
b u	Shear displacement
N p	Normal force at failure
Qp	Shear force at failure
M D	Bending moment at yield limit
M p	Bending moment at plastic limit
Ei	Modulus of elasticity of intact rock
Qcf	Shear force
Lcp	Reaction length
v	Poisson ratio of rock mass
Po	In situ stress

Abbreviations

JRC	Joint roughness coefficient
JCS	Joint compressive strength
RMR	rock mass rating
RQD	rock mass Designation
Q	rock mass quality
Jn	joint set number
Jr	joint roughness number
Ja	joint alteration number
Jw	joint water reduction factor
SRF	stress reduction factor

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Figures



Figure 1

LIDAR image, The Ratio "VV, VH, VV / VH" combination works well for distinguishing water objects, open soils, moistened agricultural fields, vegetation, and urban areas. Water in lakes is shown in dark blue, bright blue or black hues with radar signal noise. Blue hues show agricultural fields with bare soil, often sufficiently waterlogged. Fields with vegetation show a green color. Buildings of a metropolis are represented by bright green-yellow shades.

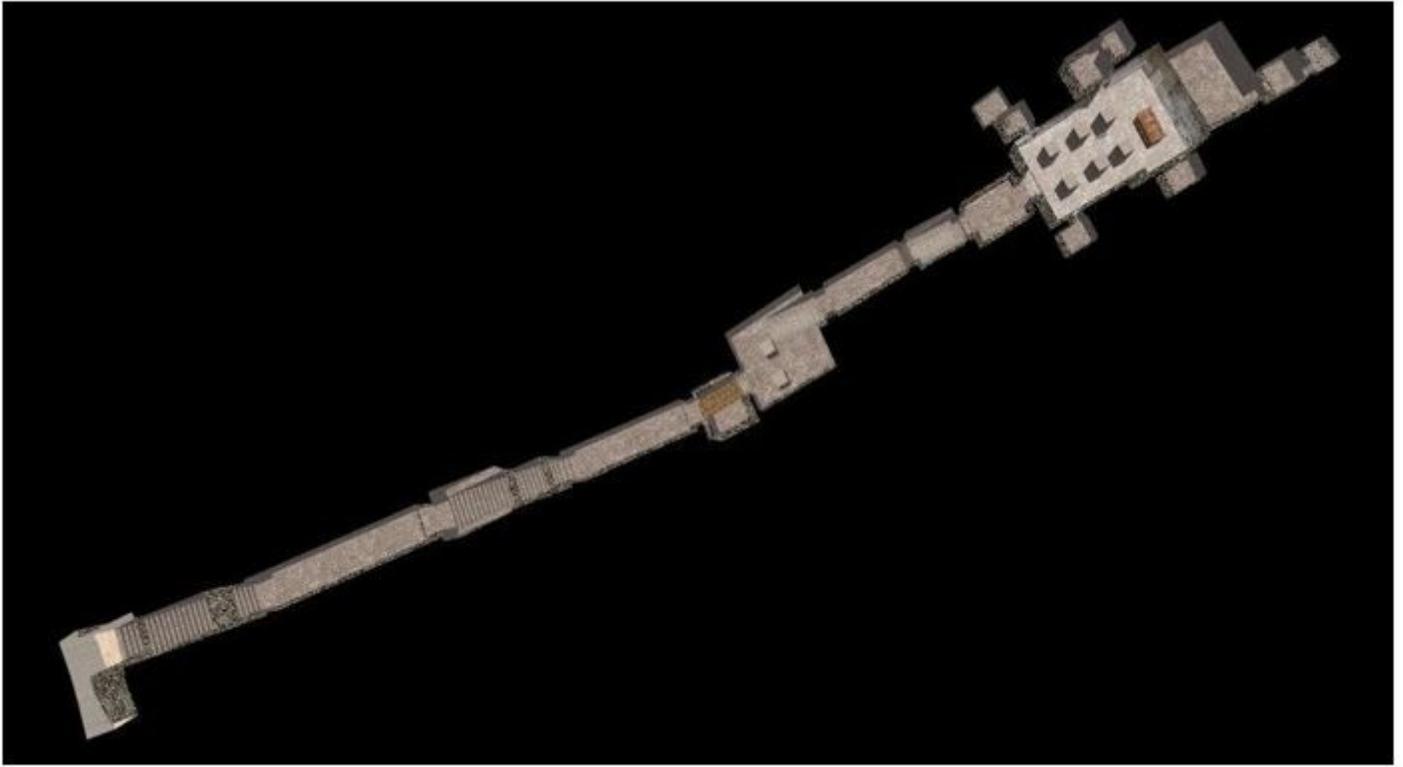


Figure 2

3D Sketchup model for the Horemheb tomb, Luxor, Egypt (KV57).



Figure 3

the entrance and corridor of the KV57 where it is whole excavated in the marl Shale layers, Chert lenses and nodules are abundant and obvious.



Figure 4

In-plane deformation patterns like vertical cracks and crown zone rock falling and intensive cracking of lintel due to over loading (geostatic loading) and impact of old and modern flash floods in particular the 1994 flood.

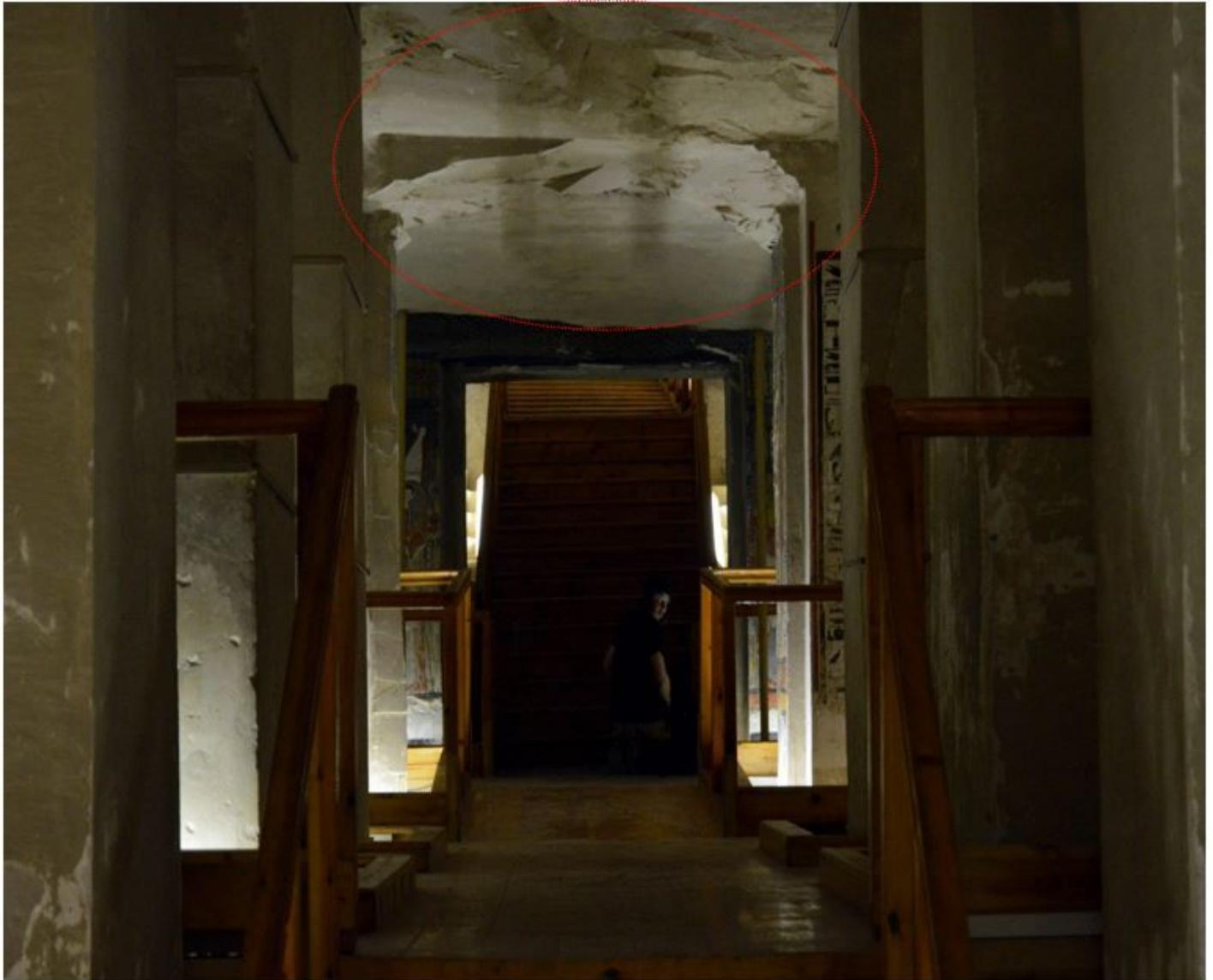


Figure 5

Extensive structural damage of crown ceiling zones and engineering failure of the structural pillars, sidewalls and Ceiling of the Corridors and Chambers in the KV57. Brittle rock, high stress conditions lead to rockbursting (the sudden release of stored strain energy) bursts manifest themselves through sudden. Extensive rock falls from the ceiling is obvious and cracks are active when the gypsum Pegs are cracked and broken.



Figure 6

Carved and decorated walls in massive Esna shale Member are in advanced state of disintegration. Showing chert lenses. The ornamented plaster on top of the chert lenses and nodules was damaged during the first flash floods that entered the tomb some 3000 years ago. During several restoration projects over the past 200 years, cracks were filled with plaster for protection and stabilization of the tomb. The impact of the 1994 flash floods on the mural paintings inside the tomb are severely obvious.



Figure 7

Urban Image. This band combination also provides a "natural-like" rendition while also penetrating atmospheric particles, smoke and haze. Vegetation appears in shades of dark and light green during the growing season, urban features are white, gray, cyan or purple, sands, soils and minerals appear in a variety of colors. The almost complete absorption of Mid-IR bands in water provides well defined and highlighted sources of water within the image. water is black or dark blue. Hot surfaces such as forest fires saturate the Mid-IR bands and appear in shades of red or yellow. One particular application for this combination is monitoring fires. Flooded areas should look very dark blue or black.

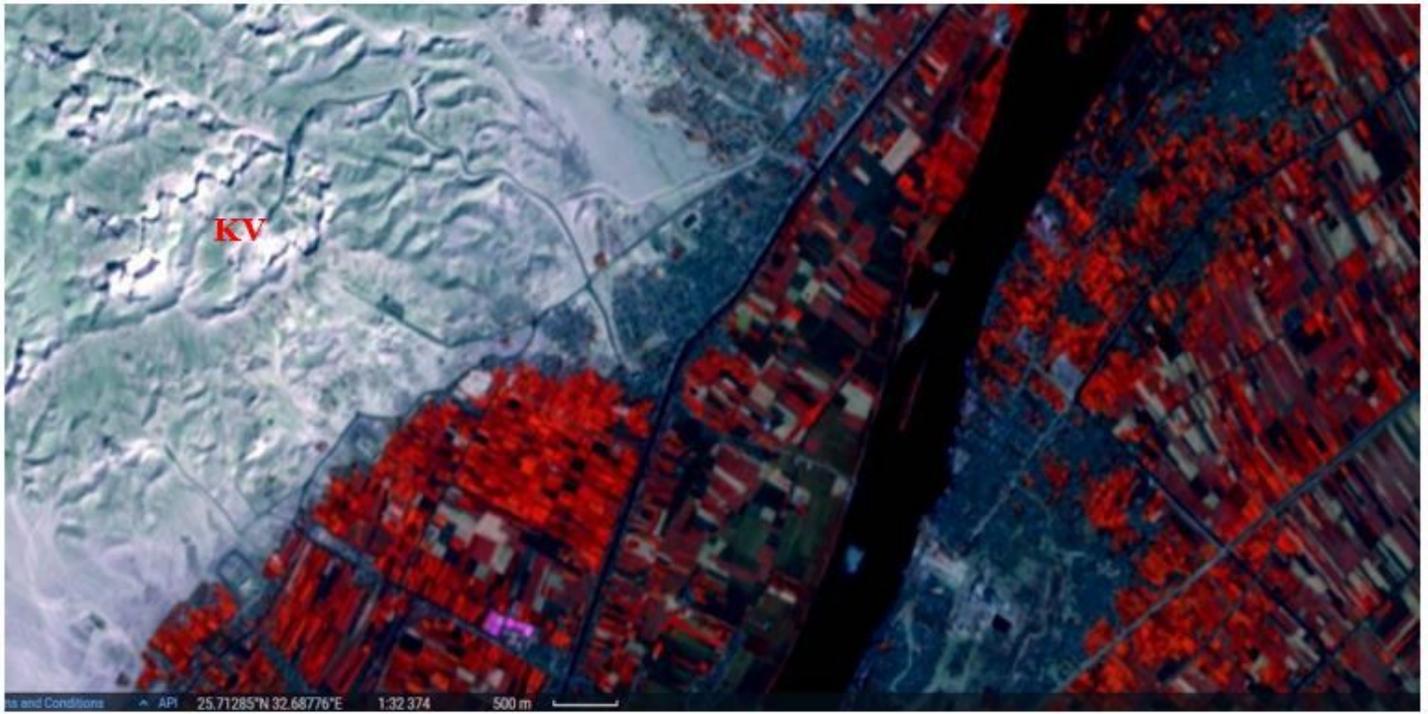


Figure 8

This band combination good for picking out land from water. In this false color image, land appears in shades of orange and green, and water appears in shades of blue.

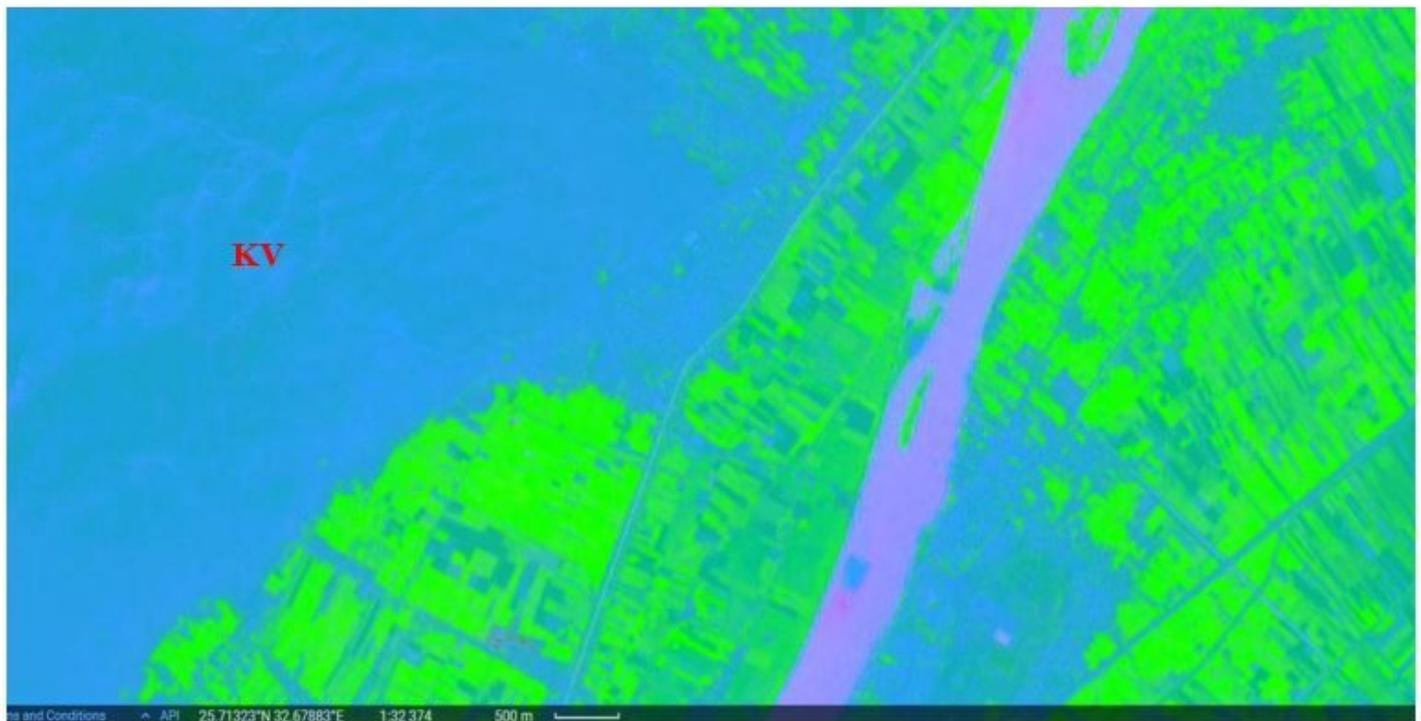


Figure 9

Index stack. It becomes readily apparent in this image stack that particular colors can be equated to different landscape features. For example, vegetation displays here as green, water as purple, and soil, rocks, and barren land as blue. Clouds also appear as a mixture of purple and magenta, so in this case these indices alone are not sufficient for differentiating clouds from water.



Figure 10

The classification map which includes four different classes for clouds (including cirrus) and six different classifications for shadows, cloud shadows, vegetation, soils/deserts, water and snow provision of associated quality indicators corresponding to a map of cloud probability and a map of snow probability.



Figure 11

Location of the Horemheb tomb (KV57) at the east (main) Valley of the Kings (KV), Luxor Egypt. Stratigraphical succession as seen. Characteristic weathering of the Thebes Formation was used to subdivide the Thebes Formation into four units, Member I to Member IV. A 30 m displacement of Member I associated to the Kings Valley Fault is located on the right-hand side approximately 40 m from the tomb of Amenmesse (KV10).



Figure 12

(DEM), Digital Elevation Model of the valley of kings and the Gebel Gurnah.

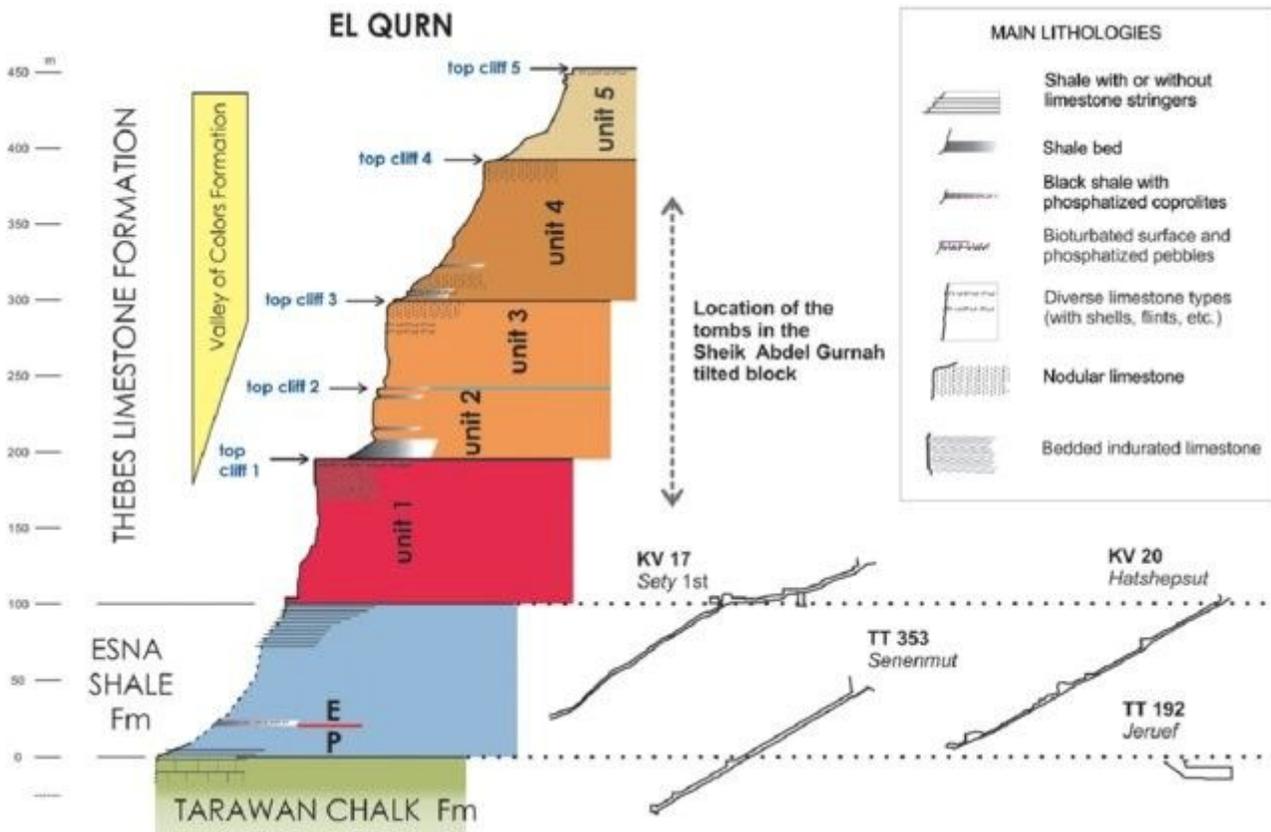


Figure 13

Stratigraphical succession on the West Bank. We show here the location of selected tombs in this succession. Tombs KV17, 20, TT353 and 192 are located in the sub horizontal bedrock. P, Paleocene; E, Eocene.

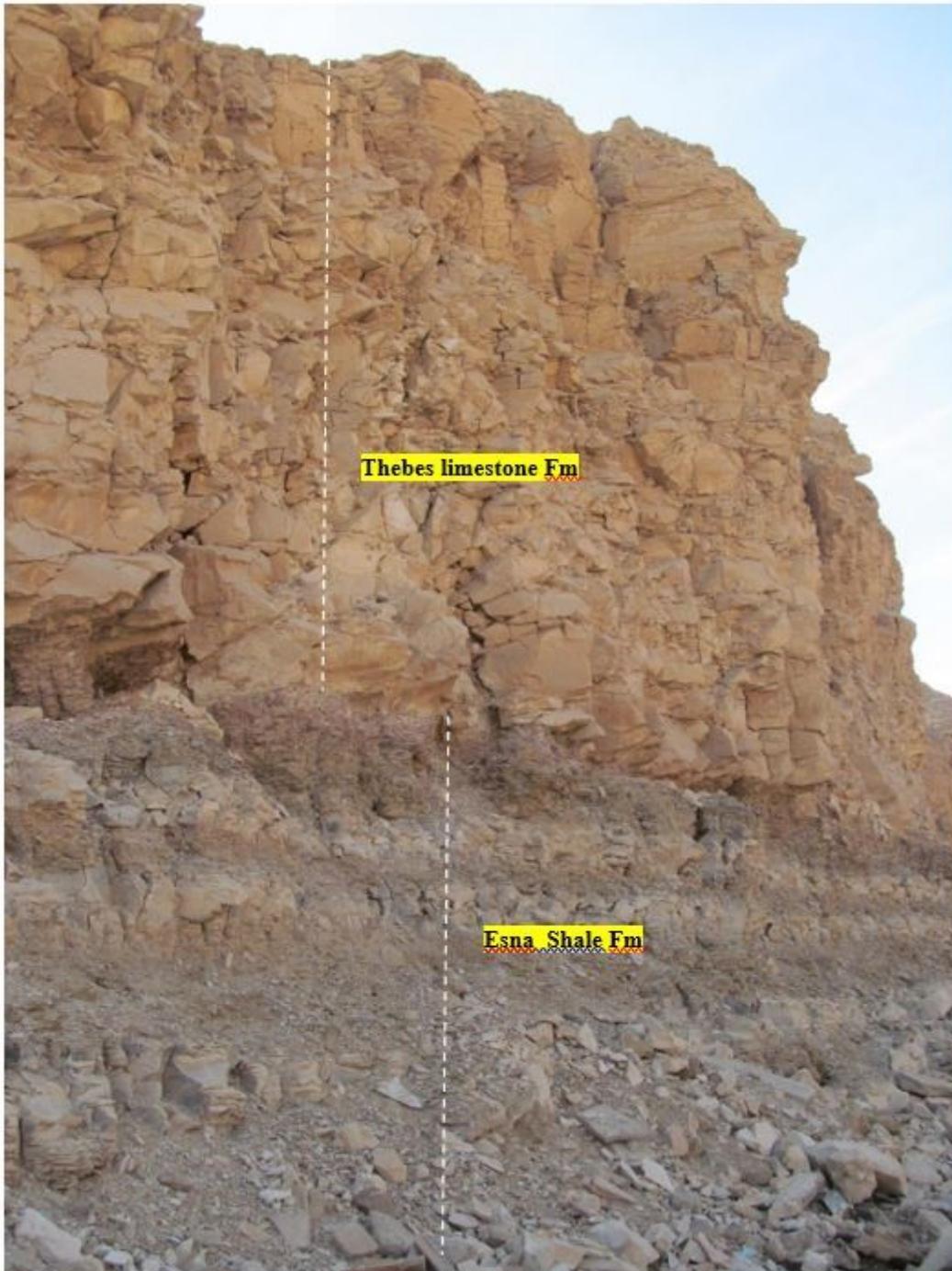


Figure 14

Abrupt contact of the Abu Had Member of the Esna Shale Formation with lithological unit 1 of the Thebes Limestone Formation. Photo taken just above the location of the KV57



Figure 15

Evidence of flash flood related erosion in the Esna Shale and vertical fissures in Unit 1 of the Thebes Limestone, delineation of the abandoned Excavations and its causeway. The subvertical wall-cuts were dug in the upper part of the Esna Shale Formation and at the base of the Thebes Limestone Formation. White arrows point to erosional gullies in the lower part of unit 1 of the Thebes Formation, in the Hanadi Member (Esna Shale Formation) and in the debris that cover the Esna Formation. Note that the gullies at the base of the Thebes Limestone and just below are commonly hollowed out, in particular on top and below the prominent base of Unit 1. These are probable evidence of flash floods. fallen blocks; unstable columnar block and open vertical fissures; screes. screes resulting from archeological excavations.

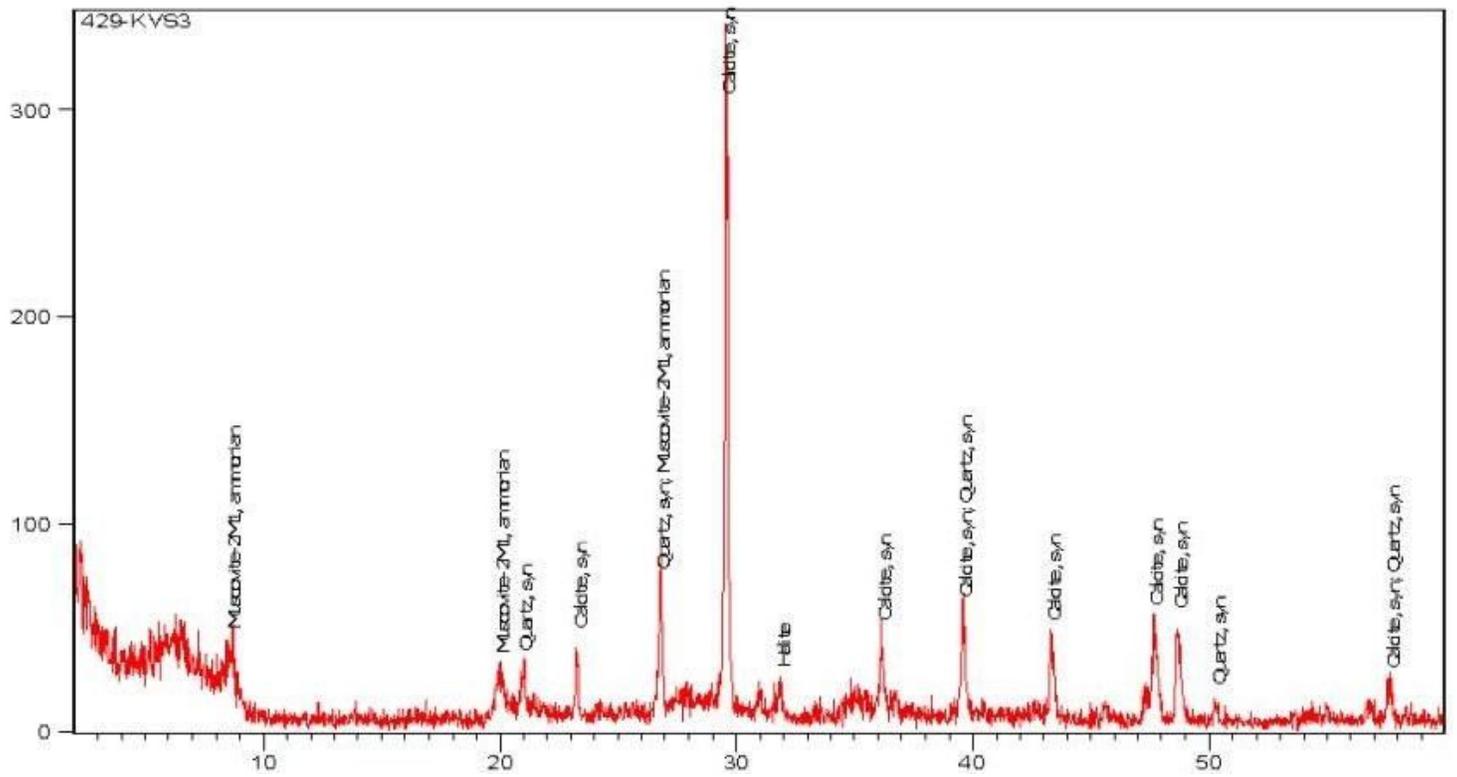


Figure 16

X-ray Diffraction results showing the bulk Mineralogy of Marl Shale (Calcite/ Smectite) where the Horemheb tomb (KV57) is excavated.

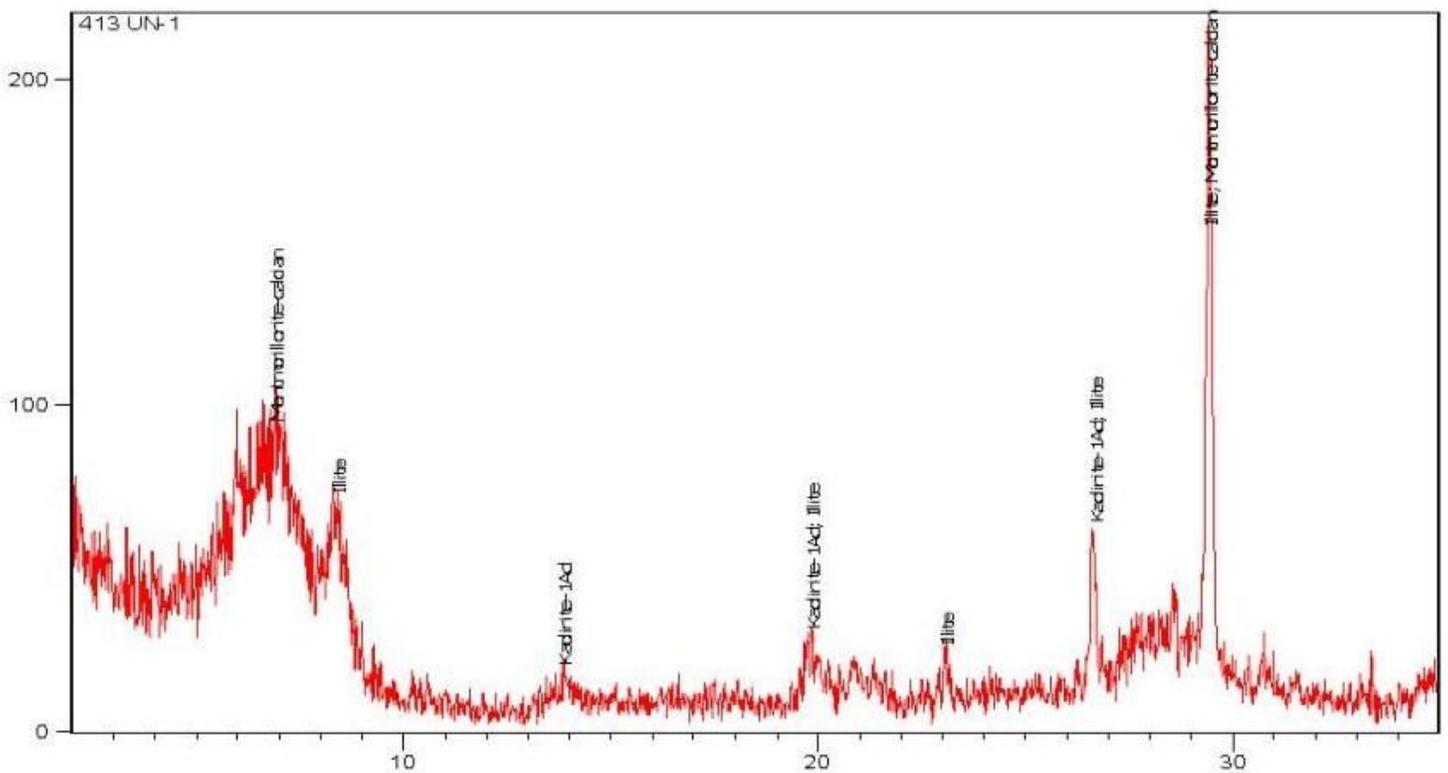


Figure 17

X-ray Diffraction pattern showing the clay minerals of natural or air treated untreated clay fractions sample from Esna shale Member, where the Horemheb tomb (KV57) is excavated.

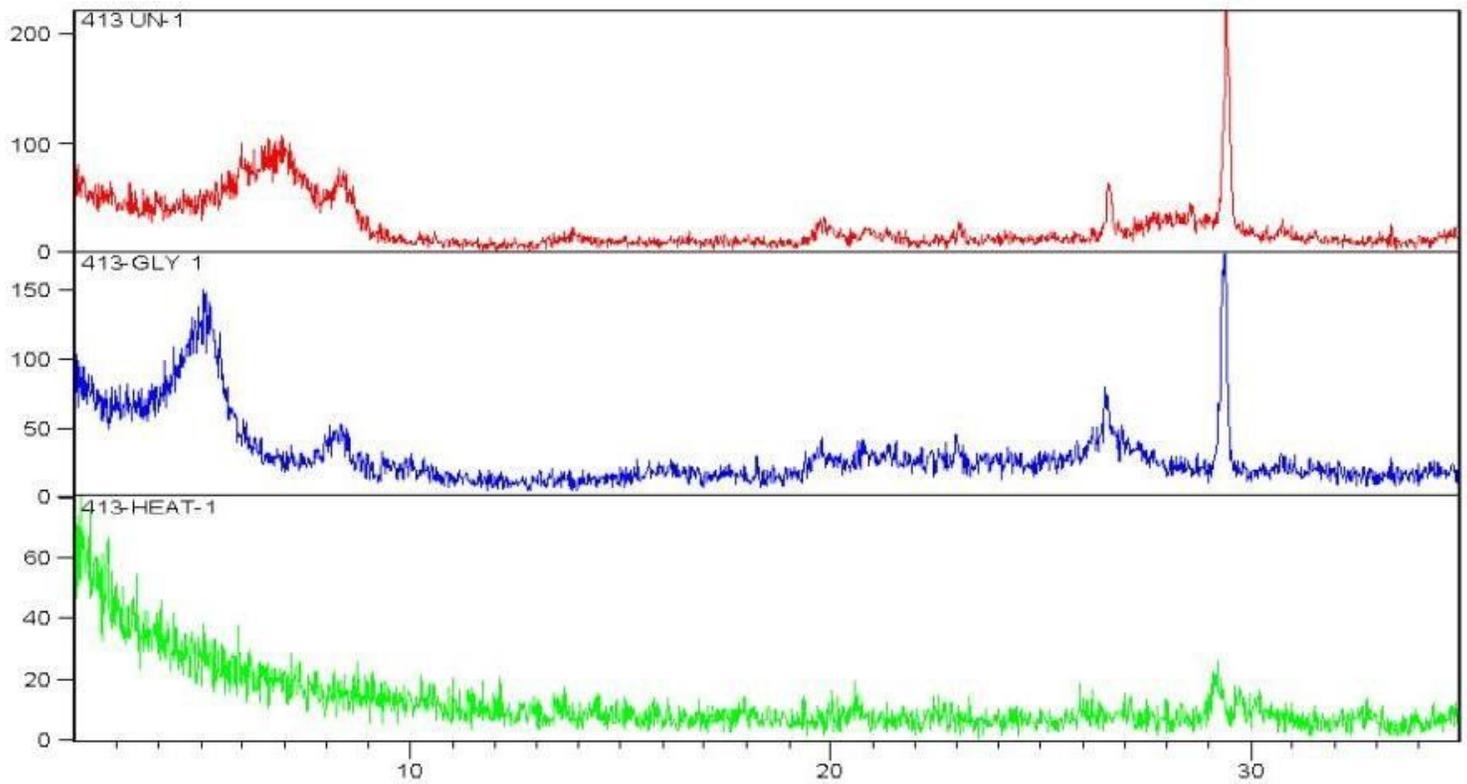


Figure 18

XRD for the air dried, ethylene glycol treated, and heated to 550C clay fractions from samples of Esna shale, showing decrease and disappearance of peak of Illite/Smectite (I/S) and the present of the Montmorillonite.

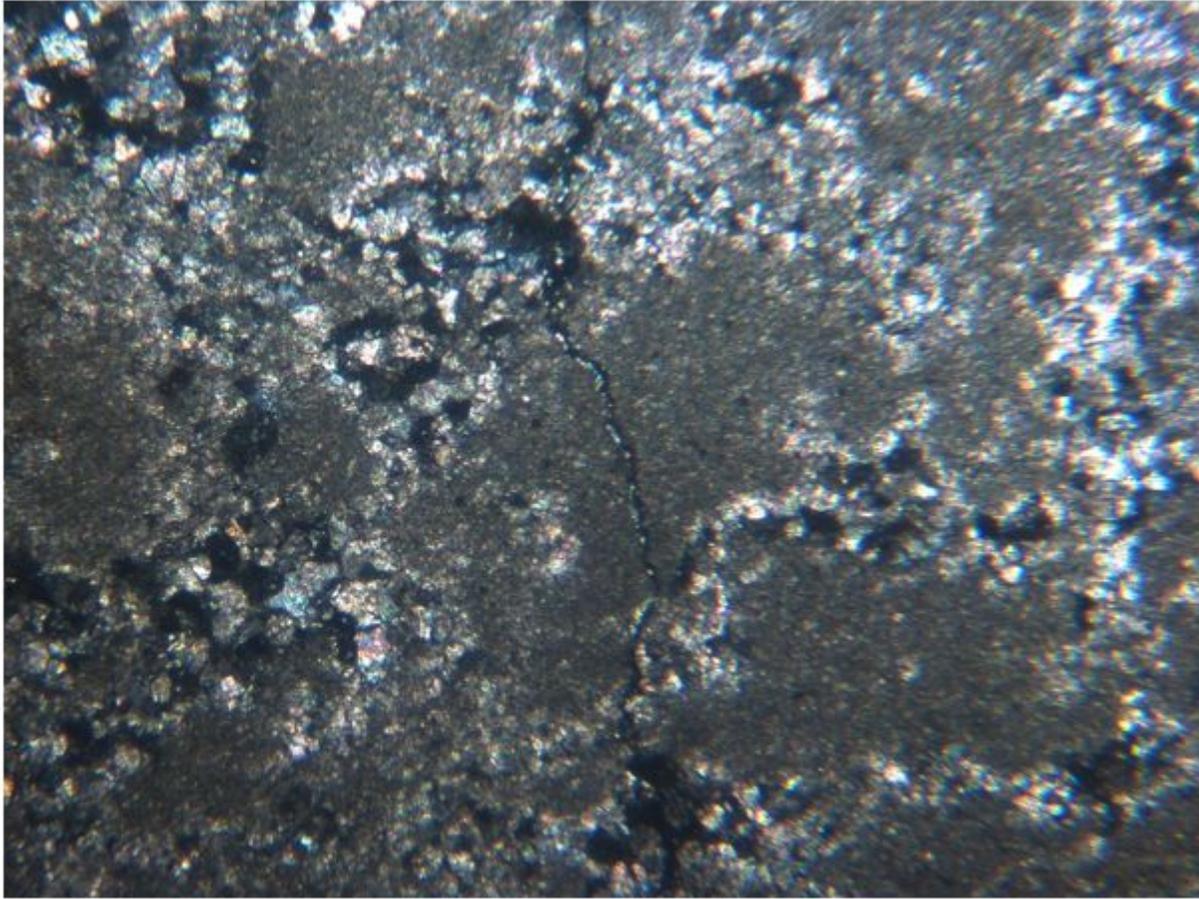


Figure 19

C.N. Microscopic photograph shows The marl sample from Member I is very fine-grained to fine-grained. Considerable amounts of cavities and microvioletlets filling by recrystallized dolomite are observed in the micritic calcite matrix. The rock is very to fine-grained and composed mainly of calcite and dolomite as the essential components associated with minor amount of clay minerals and rare amounts of microcrystalline quartz, iron oxides and opaques. Calcite represents the matrix of the rock and occurs as very fine-grained (micrite), anhedral to subhedral interlocked crystals. Dolomite occurs as very fine to fine-grained, euhedral to subhedral crystals and filling microvioletlets and cavities. Quartz is detected as very fine-grained crystals scattered in the matrix. Some pores of irregular shapes and various sizes are observed scattered in the rock. Some parts of the sample are stained by iron oxides

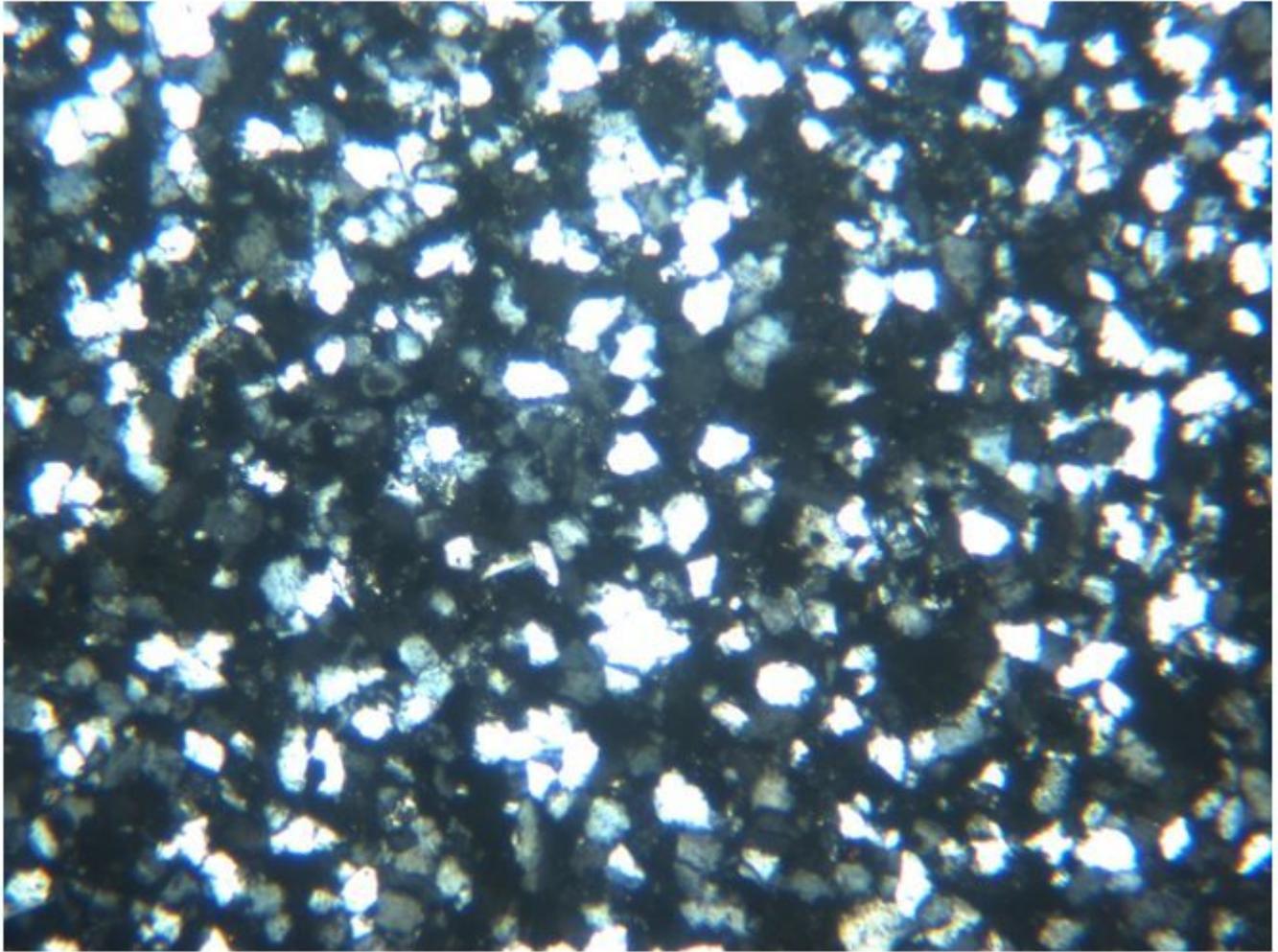


Figure 20

C.N. Microscopic photograph shows the Esna shale sample is very fine to fine-grained (mainly sand size), well sorted that is cemented by minor amounts of iron oxides, clay minerals and carbonates. The sample is porous where pore spaces of different sizes are observed. The rock is composed mainly of quartz and feldspar grains cemented by minor amounts of iron oxides, clay minerals and calcite. Rare amounts of muscovite, biotite, hornblende and opaque minerals are observed in the sample. Quartz occurs as very fine to fine grains of subrounded to angular shape. Feldspars occur as fine grains that are observed in different parts of the sample. Opaque minerals occur as very fine to fine-grained crystals, scattered in the sample. Some parts of the sample are stained by traces of iron oxides

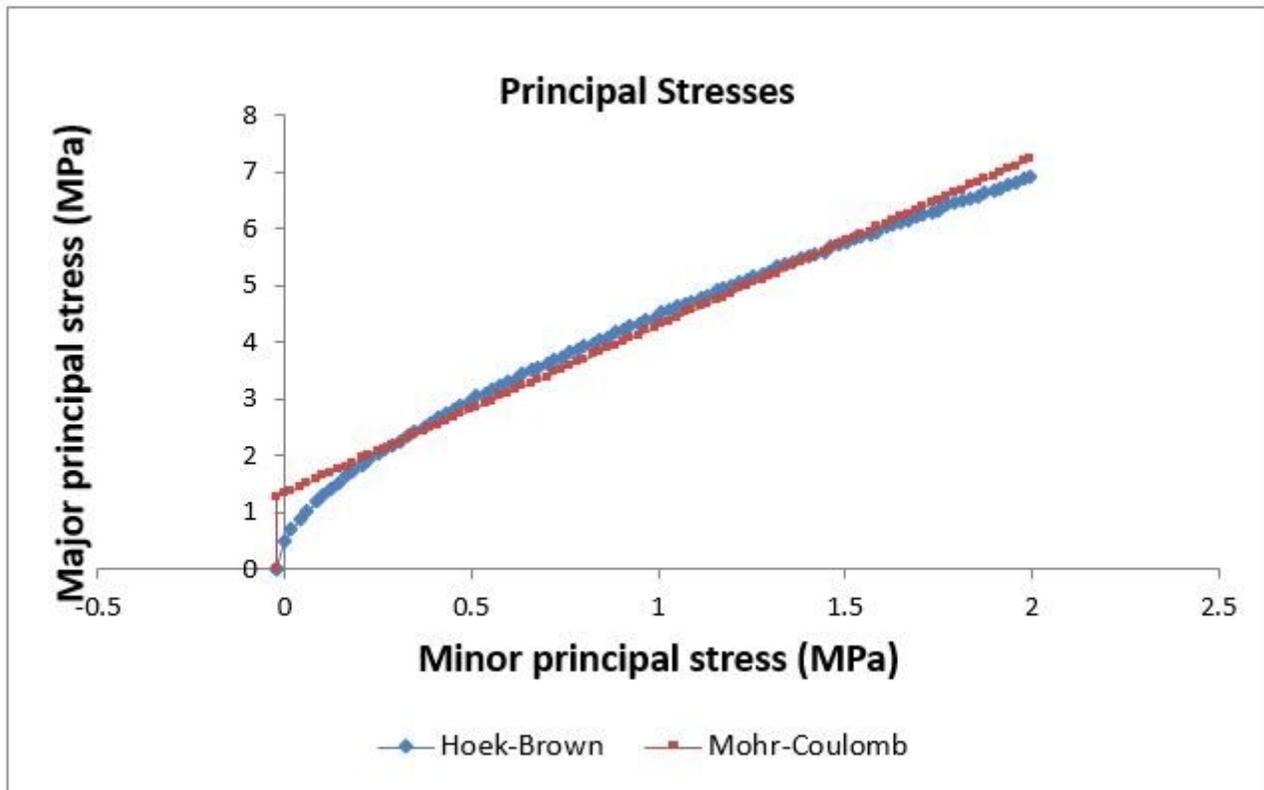


Figure 21

Major and minor principal stress curve of marl limestone (KV57) using the RocLab program.

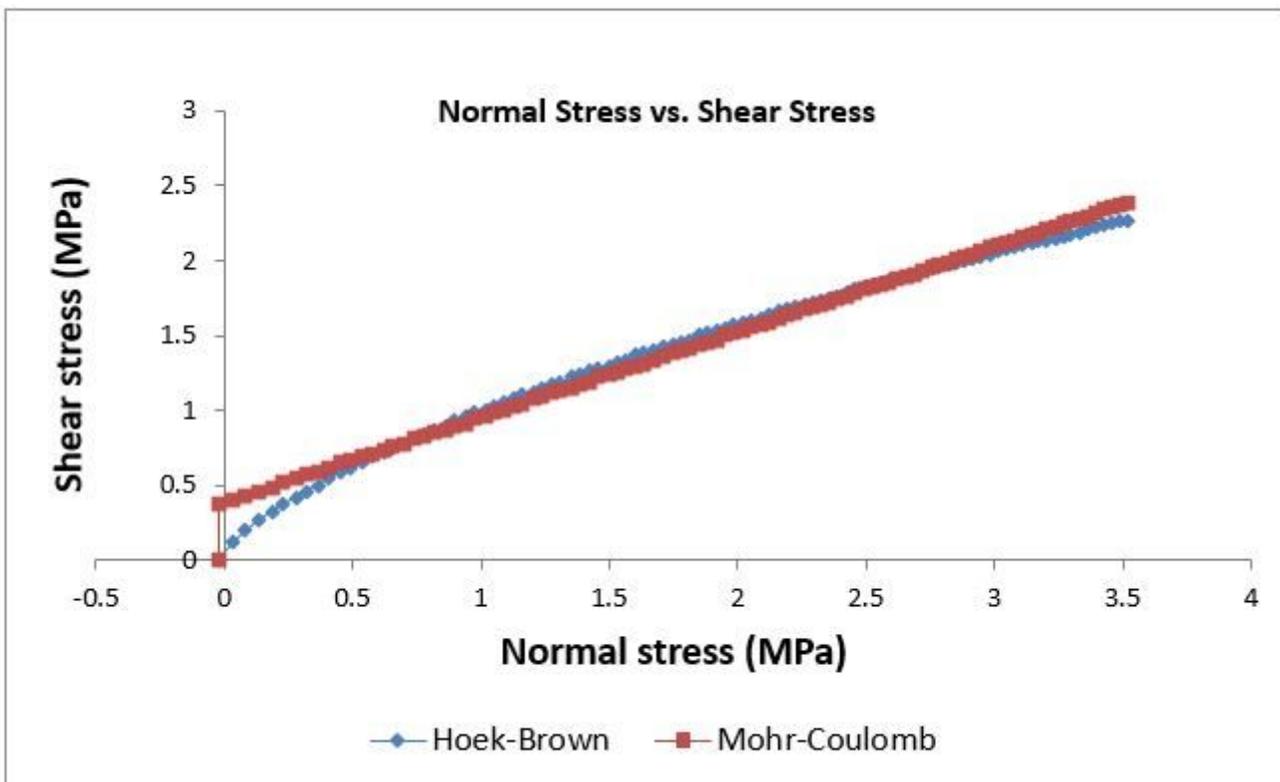


Figure 22

Shear stress-Normal stress curve of Marl limestone (KV57), using the RocLab program.

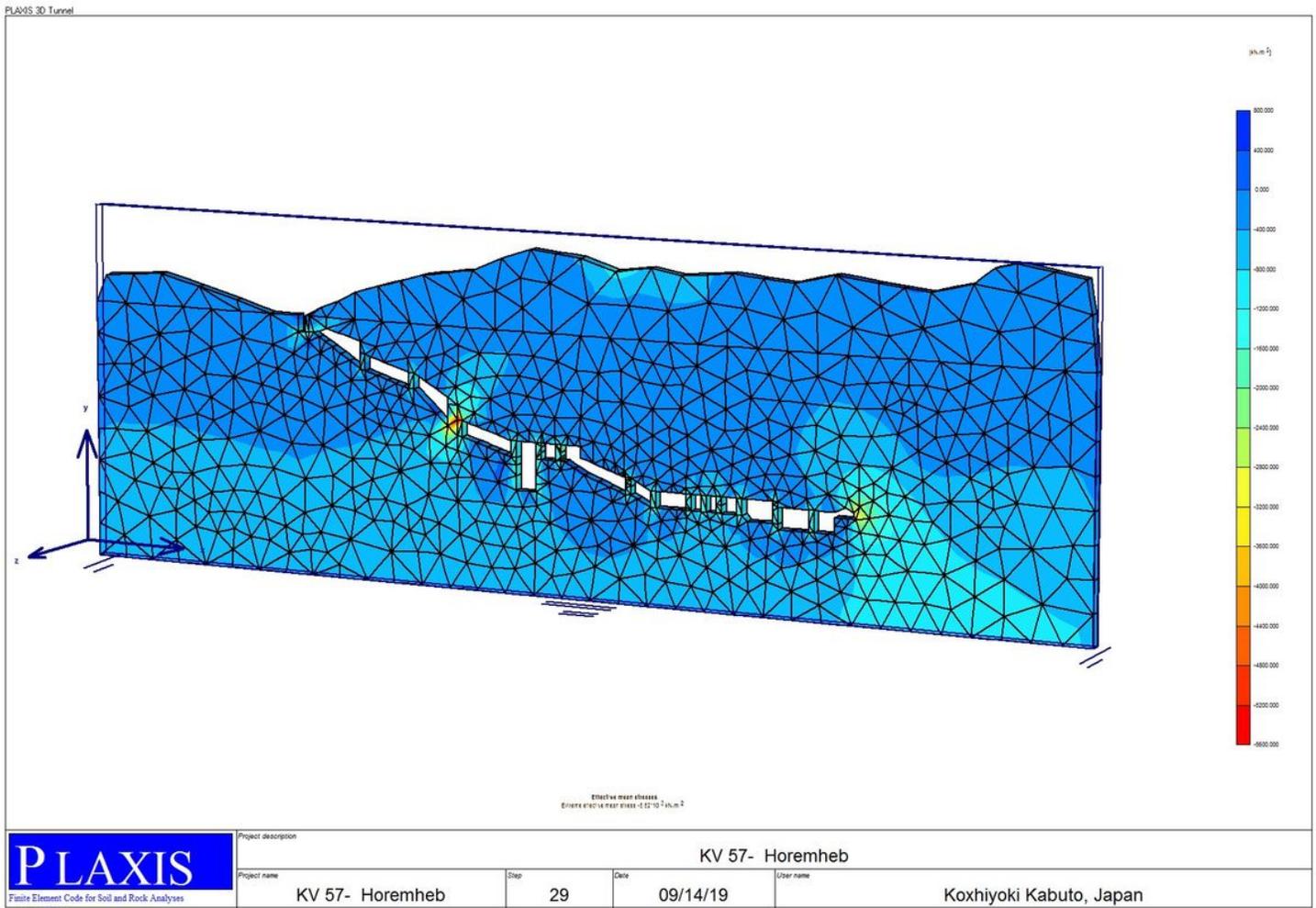


Figure 23

Effective mean stresses for the supported rock pillars and sidewalls in KV57, the extreme value is $5.52 \cdot 10^3 \text{ kN/m}^2$.

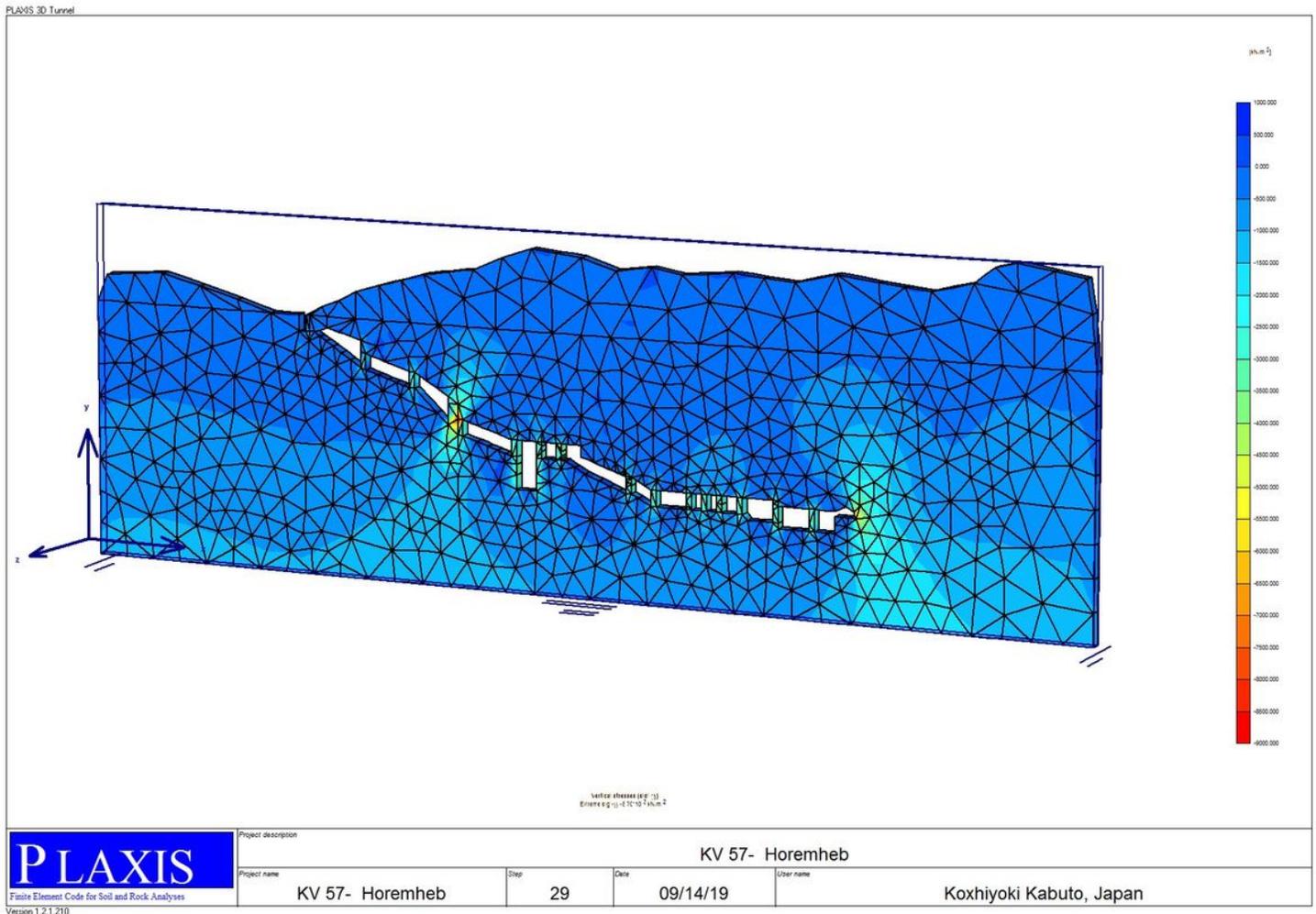


Figure 24

Vertical stresses (σ_{yy}) for the supported rock pillars and sidewalls in KV57, the extreme value is $8.70 \cdot 10^3 \text{ kN/m}^2$.

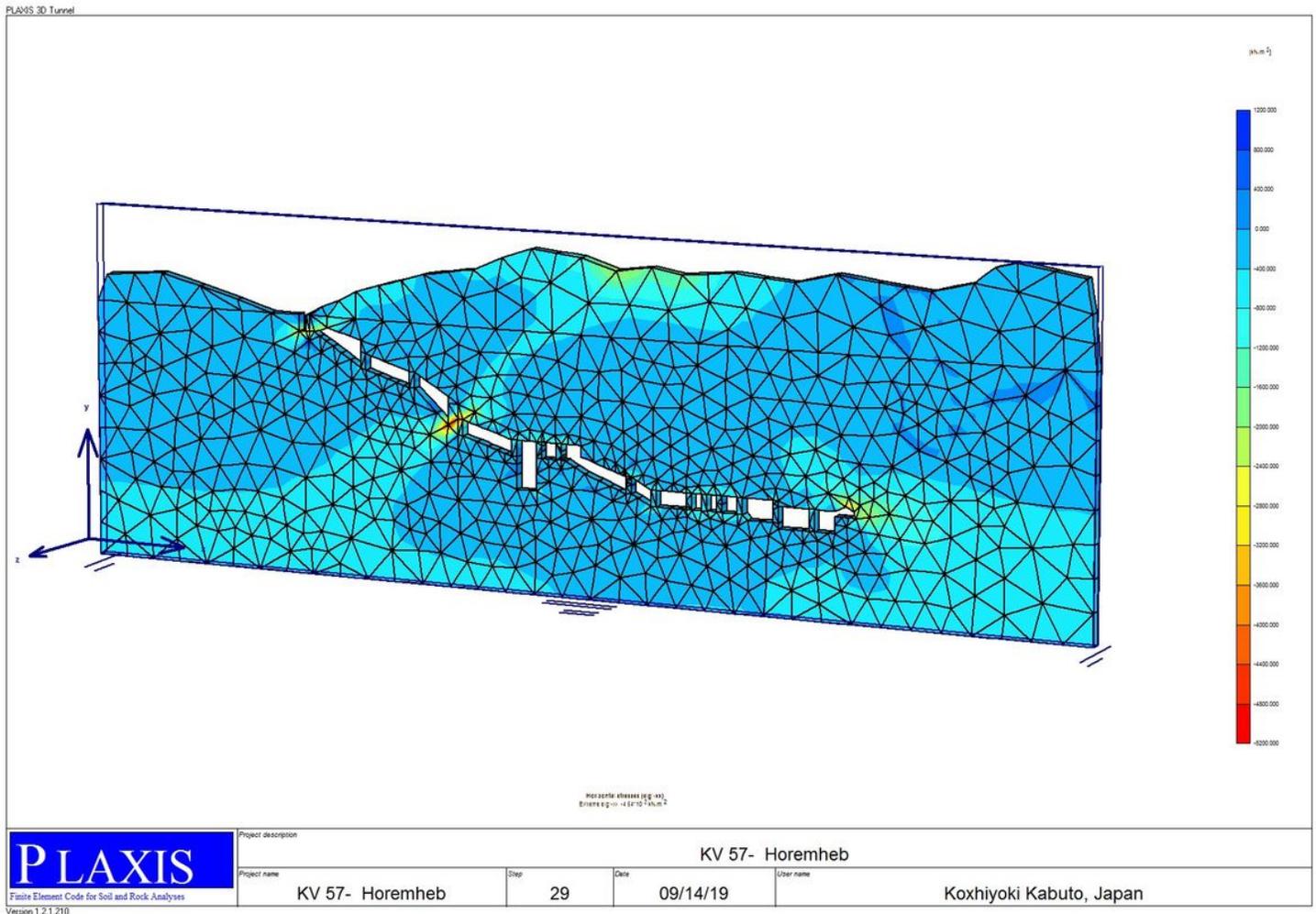
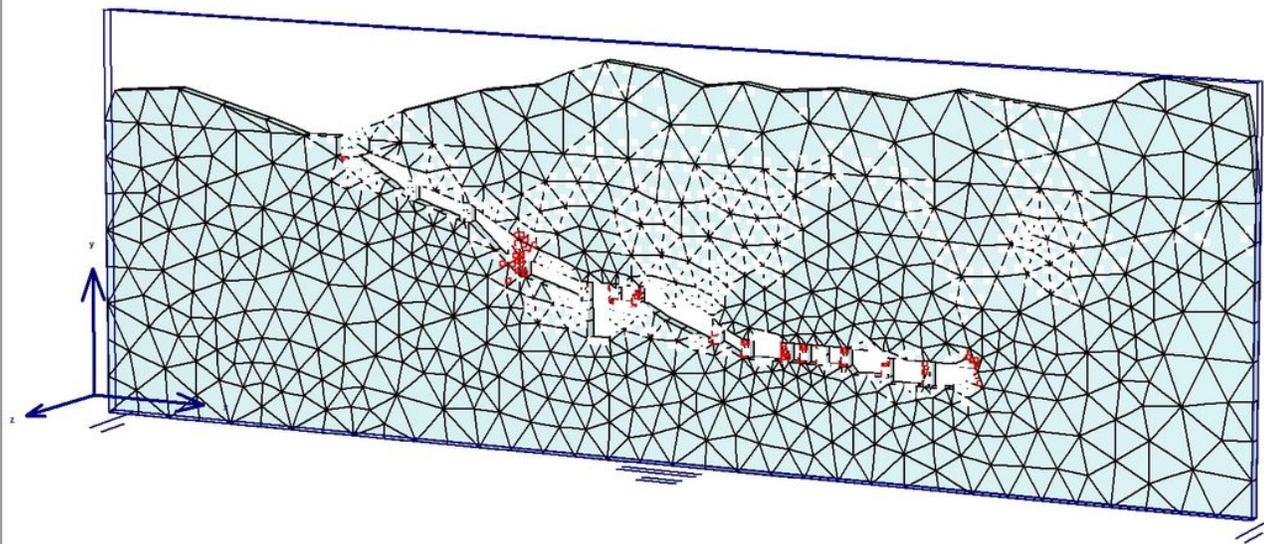


Figure 25

Horizontal stresses (sig xx) for the supported rock pillars and sidewalls in KV57, the extreme value is $4.94 \cdot 10^3 \text{ kN/m}^2$.



Plastic Points
 □ Mohr-Coulomb point ● Tension cut-off point

PLAXIS

Finite Element Code for Soil and Rock Analyses
 Version 1.2.1.210

Project description		KV 57- Horemheb				
Project name	KV 57- Horemheb	Step	29	Date	09/14/19	
					User name	Koxhiyoki Kabuto, Japan

Figure 26

Plastic points (Mohr-Coulomb and Tension cut-off points) for the supported rock pillars and sidewalls in KV57.

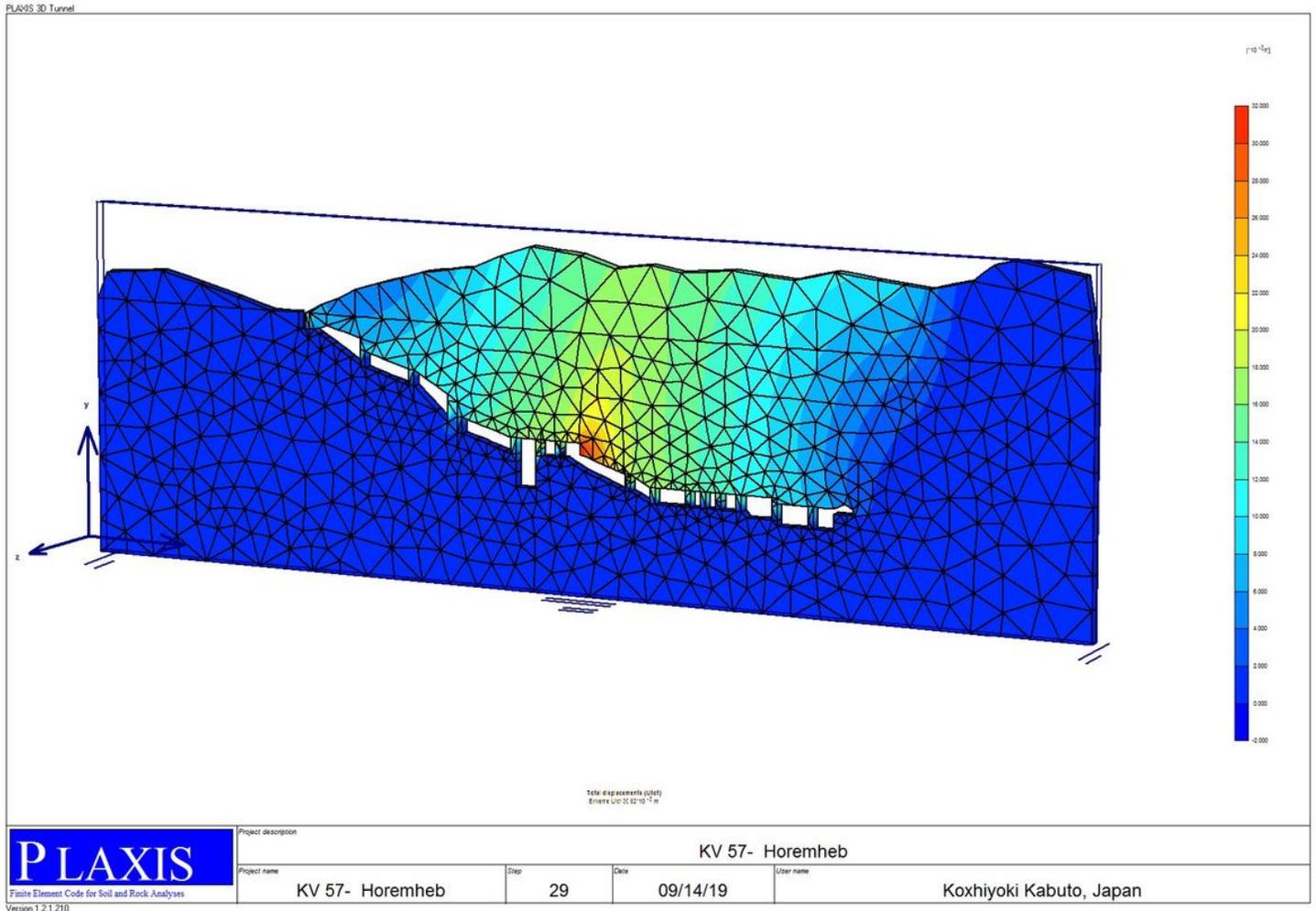


Figure 27

Total displacement (U_{tot}) for the supported rock pillars and sidewalls in KV57, the extreme value is 30.92mm.

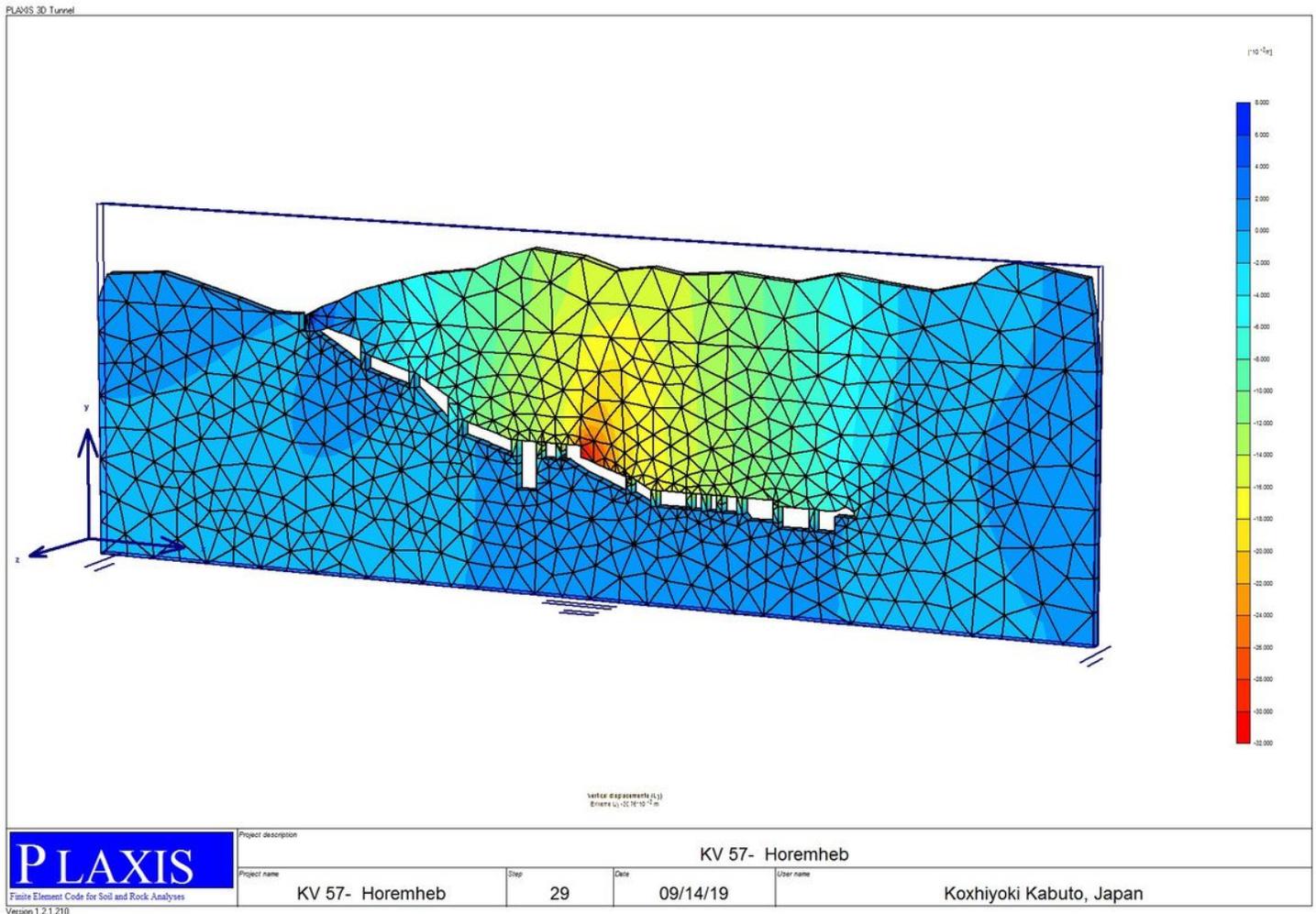


Figure 28

Vertical displacement (U_y) for the supported rock pillars and sidewalls in KV57, the extreme value is 30.76mm.

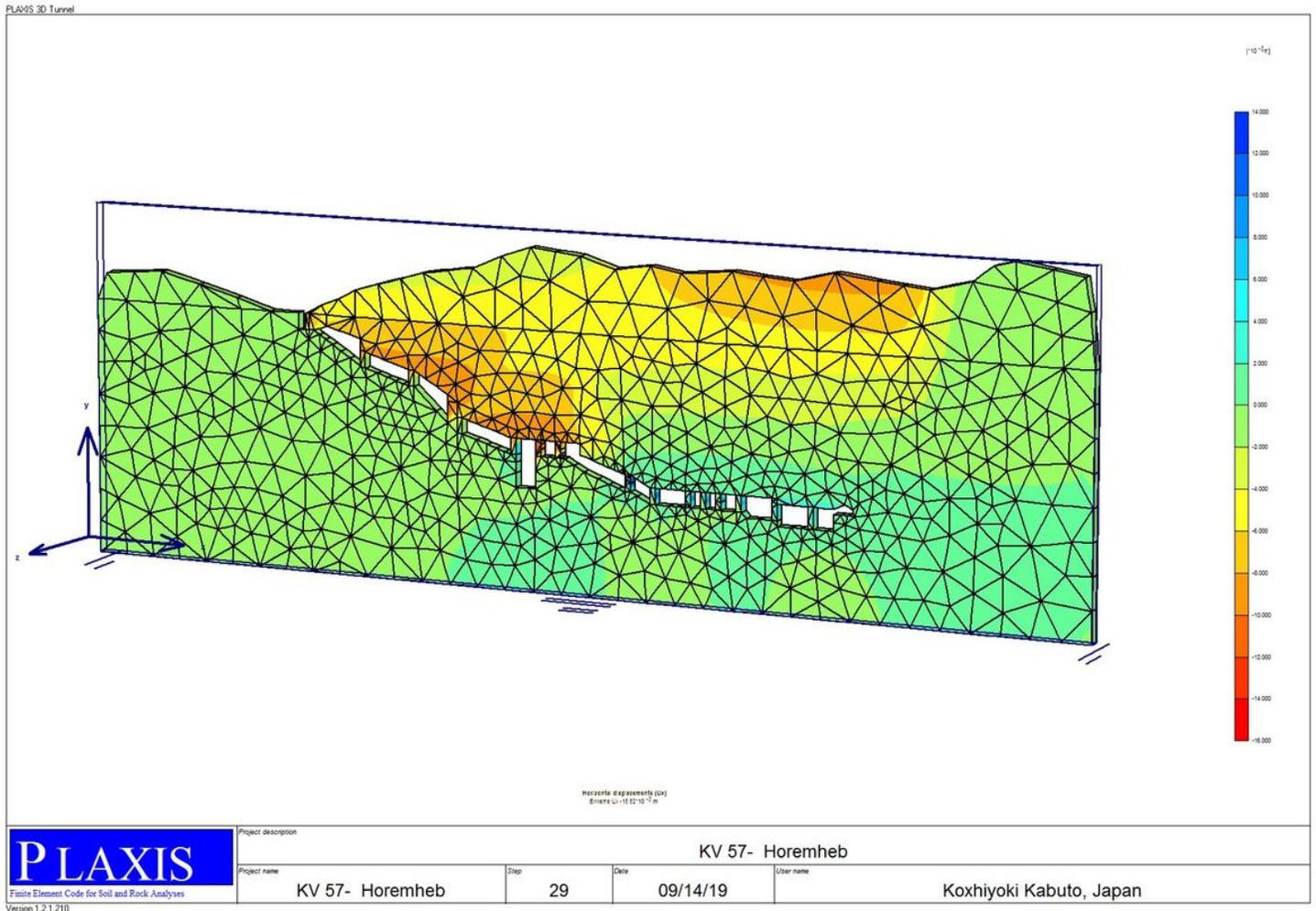


Figure 29

Horizontal displacement (U_x) for the supported rock pillars and sidewalls in KV57, the extreme value is 15.52mm.

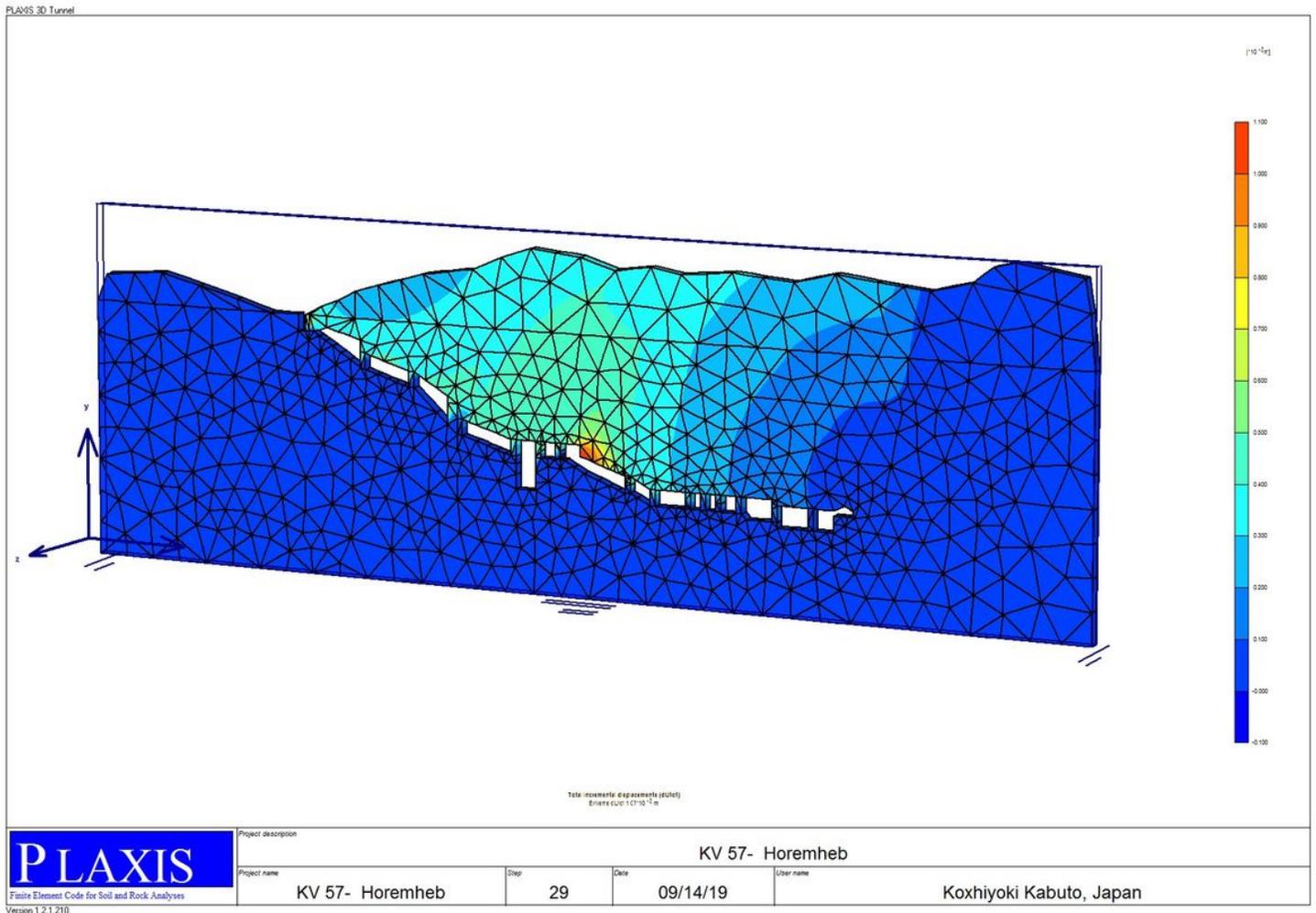


Figure 30

Total incremental displacement (dUtot) for the supported rock pillars and sidewalls in KV57. The extreme value 1.07mm.

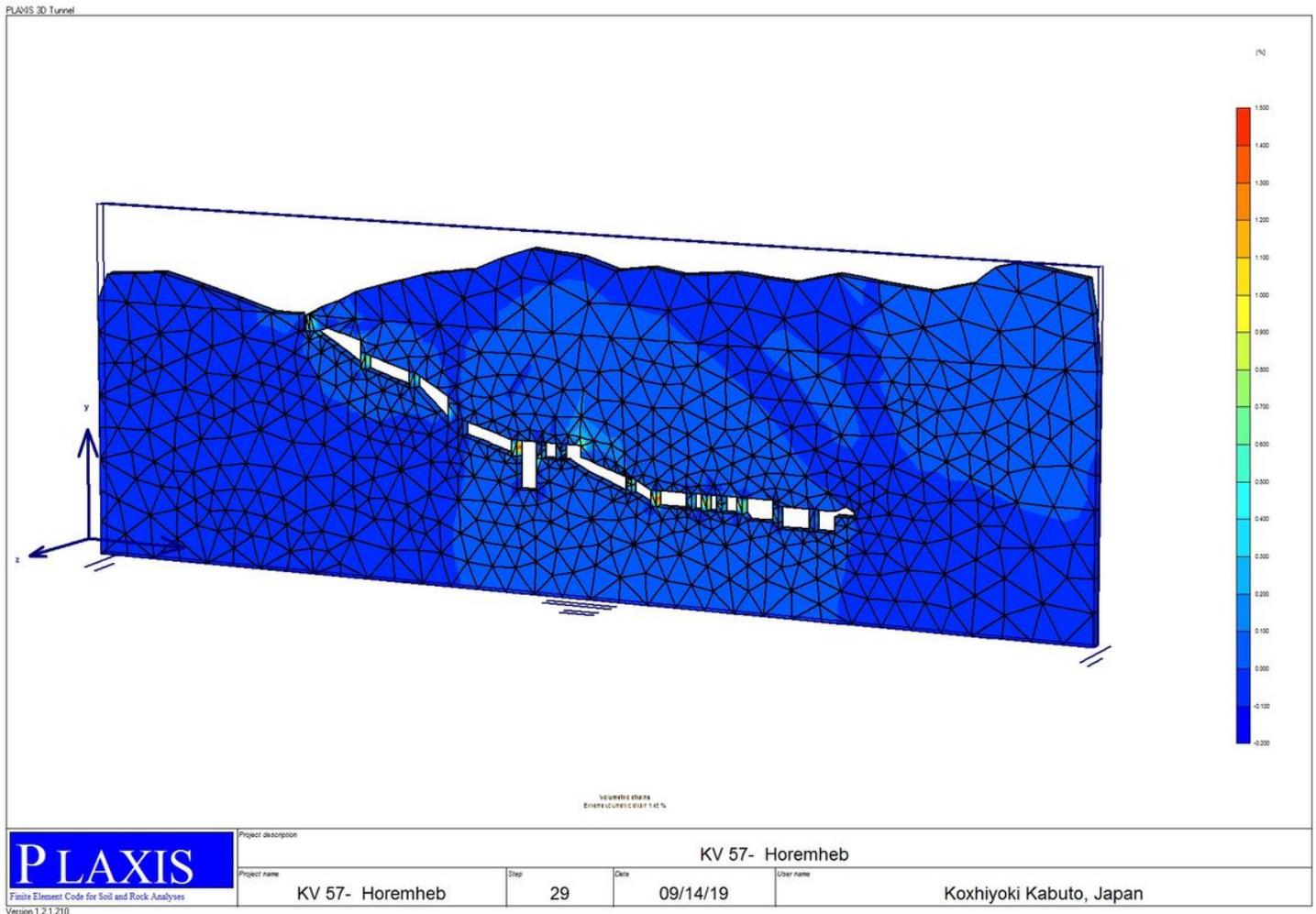


Figure 31

Volumetric strains for the supported rock pillars and sidewalls in KV57. The extreme value 1.45 %.

Supplementary Files

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